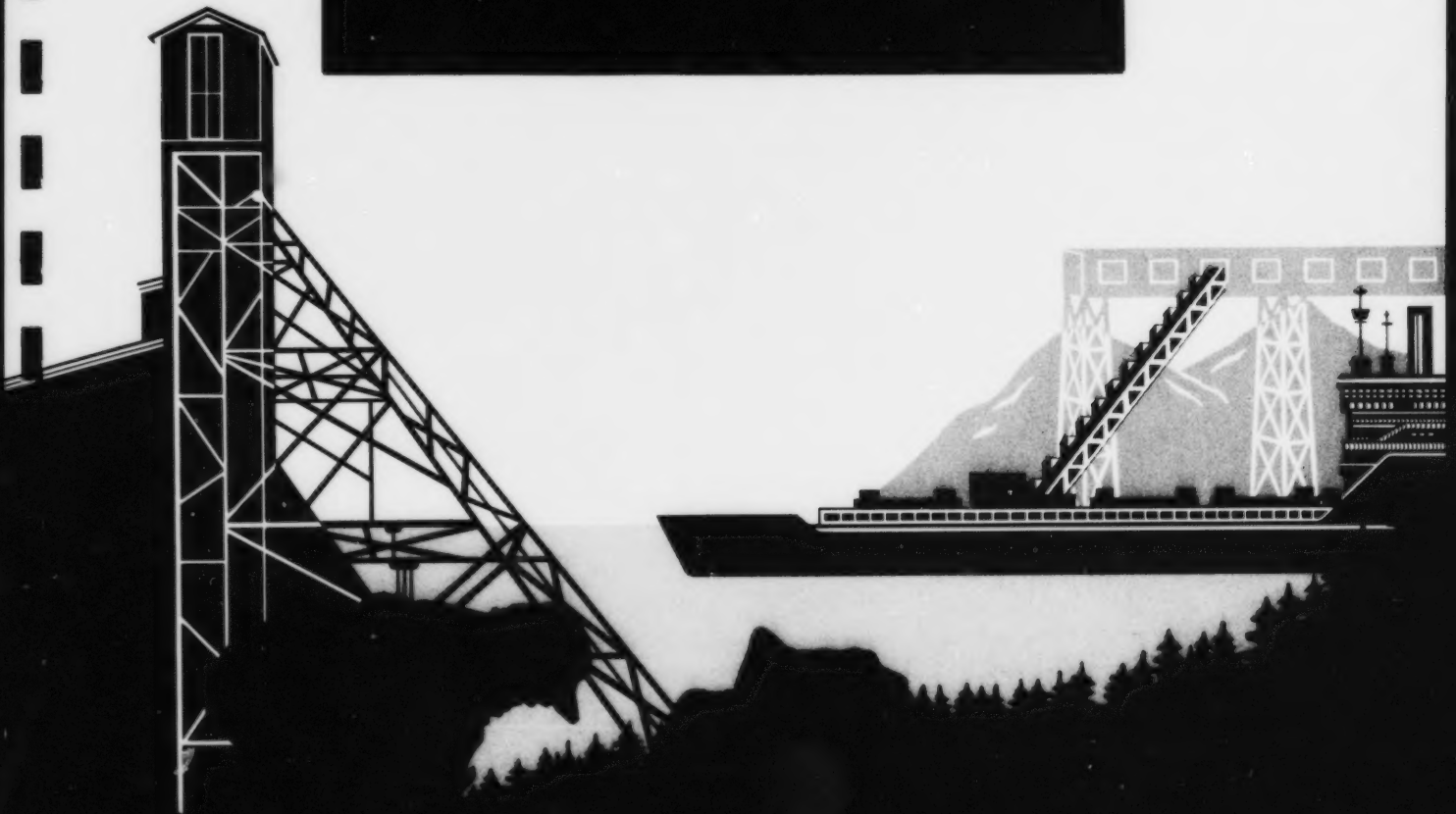
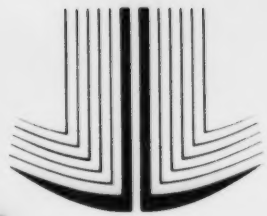


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AN ASSESSMENT OF THE
HYDROCARBON AND COMPRESSED AIR STORAGE
POTENTIAL OF NOVA SCOTIA SALT DEPOSITS

BY

Nolan, Davis & Associates (N.S.) Limited
Halifax, Nova Scotia

FOR

Mineral Policy Sector
Energy, Mines and Resources Canada

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PART A
INTRODUCTION



PART A: INTRODUCTION

1.0 PROJECT RATIONALE

Nolan, Davis & Associates Limited of Halifax, Nova Scotia, in association with PB-KBB Incorporated of Houston, Texas, have undertaken a study of the suitability of utilizing Nova Scotia salt deposits for underground cavern development and storage. Substances considered for storage include crude oil, liquefied petroleum gases (LPG), natural gas, and compressed air. The study originated from a Request for Proposal from the Department of Supply and Services Canada (DSS File No. OSC86-00117-(014)/A) and is funded by the Canada-Nova Scotia Mineral Development Agreement 1984-89.

Interest in developing salt caverns for hydrocarbon storage in the Strait of Canso area was strong in the late 1970's, largely because of the United States Government's ambitious Strategic Petroleum Reserve (SPR) Program, which developed as a response to the threat of interrupted petroleum supplies from foreign countries. After a brief period of extensive exploration, site selection, and cavern design work (including the actual brining of two caverns near the Strait of Canso), interest in the concept waned and subsequent activity slowed and eventually ceased, due to a variety of economic, political, and technical factors.

The purpose of the current study is to re-assess the potential for utilizing Nova Scotia's abundant salt deposits for hydrocarbon storage, and/or compressed air energy storage related to peak shaving, possibly in association with the development of Tidal Power in the Bay of Fundy. The general merit of siting underground storage facilities with energy-related uses in a region with relatively high energy costs such as Atlantic Canada is recognized. The technical and economic factors can be weighed and objectively assessed, taking into account the future potential of large-scale regional energy developments such as the Venture Gas Field, Hibernia, and Fundy Tidal Power.

2.0 INVESTIGATION METHODOLOGY

The project was undertaken in three phases:

1. Initial Assessment
2. Data Collection and Compilation
3. Assessment of Storage Feasibility

The Initial Assessment consisted of collecting all readily available geological, geophysical, engineering, environmental, economic, and other relevant data on each individual deposit within the four designated geographical areas of interest: Hants-Colchester, Cumberland, Canso-Bras d'Or, and Sydney.

Data forms for the preliminary assessment of available geologic data were drafted and the basic data on the salt occurrences were compiled. Those sites which could be dropped from consideration for obvious reasons (such as insufficient salt thickness) were eliminated from further immediate consideration. For those sites with insufficient data, an assessment was made of the further data required to properly assess the potential for development of storage caverns.

The second phase, Data Collection and Compilation, involved collecting supplementary data for the various sites not eliminated in the initial screening. New information which became available since the publication of Boehner's (1986) report was collected from the assessment files of the Nova Scotia Department of Mines and Energy (NSDME). Relevant data from other government departments and agencies as well as local libraries, research institutions, and private companies were also collected and assessed during this phase.

Field visits were made by geological personnel from Nolan, Davis & Associates and Mr. Bill Bishop, Chief Engineer with PB-KBB Incorporated, to sites of interest to the study, such as the underground Pugwash salt mine and Domtar's solution salt mining operation at Nappan. Drill cores from the various salt deposits of interest were examined at the NSDME core storage facility in Stellarton, Nova Scotia.

Summary data tables were compiled based on the information collected, and formed the basis for assessment of the potential for development of storage caverns for the four substances being considered. Short lists of the best potential sites for storage within each geographic area were drafted, based solely on current geologic information.

Phase three consisted of the actual assessment of storage feasibility. During this phase of the study, the various technical, environmental, and economic assessment factors were applied to each of the geologically most favourable sites to further refine the selection of the overall best sites. The minimum required depth and salt thickness for each of the four storage substance categories, as well as other technical factors relating to the geology of the sites, were reviewed relative to the available data.

Environmental considerations such as brine disposal requirements and water availability which can strongly affect costs were assessed in this phase also. Other environmental concerns related to potential for hydrocarbon spills or leakage were also considered.

Economic factors which will affect the suitability of specific sites, including proximity to storage substance source, distribution system and market, availability of water and brine disposal were assessed for each of the geologically most favourable sites. As well, the volume of storage that can be developed per site was estimated.

The result of all of the data compilation and assessment is a list of the most suitable sites for development of salt cavern storage facilities relative to hydrocarbon storage and compressed air energy storage. As well, discussion is provided on the technical, economic, and environmental aspects of the development and operation of storage facilities at the recommended sites. Finally, recommendations are provided concerning the areas where further investigation efforts should be directed.

3.0 HISTORY OF SALT CAVERN UTILIZATION

The creation of large underground caverns in bedded and domal salt for storage of natural gas, crude oil, and liquefied petroleum gases has been practiced throughout the world for many years. Storage of liquids in salt caverns was initiated in the early 1920's (Hardy, 1978). In more recent years, caverns in salt deposits as well as hard rock have been used to store bulk products varying from grain and molasses to hazardous wastes. Salt caverns have recently been used by electrical utilities for compressed air energy storage in association with re-timing cyclic power.

A number of advantages are realized from using underground salt caverns for storage as opposed to surface tank farms. Salt has a variety of physical properties which are highly desirable for use as hydrocarbon storage cavities. It is very low in permeability, has a compressive strength comparable to concrete, seals fractures by plastic flow, and from a long-term stability standpoint, controlled cavities may be developed which provide the most optimal orientation with respect to in situ stresses. Storage of large volumes of hydrocarbons in salt cavities is considerably less costly than above-ground tank farms, as well as being environmentally safer and aesthetically more appealing.

Large underground storage cavern facilities have been developed in the United States, Canada, France, Germany, and Japan among other nations. Germany developed a number of salt caverns prior to and during the Second World War to safely stockpile crude oil reserves and other refined products. During the post-war industrial expansion, Germany continued development of salt storage caverns, largely in the northwest part of the country adjacent to the North and Baltic Seas, where vast salt dome deposits are located.

The program was accelerated by the German government as a result of the 1971-72 oil embargo, when each refinery was required to store two to three months reserve supply of crude oil (Home Oil et. al., 1979). Approximately 100 salt caverns are currently in use in Germany, with a combined storage capacity in excess of 32 million cubic metres (200 million barrels).

In France, the major underground storage facilities are located in the southeast part of the country, in an area north of Marseille. The

total storage capacity is approximately 11 million cubic metres (70 million barrels). Britain currently has one salt cavern used to store natural gas. In Denmark, a salt cavern natural gas storage project was recently completed with a capacity of 238 million cubic metres (Haddenhorst and Quast, 1983).

Japan is the largest importing country of hydrocarbons in the world because of its lack of natural resources. In recent years, the demand for liquefied petroleum gases for domestic and industrial needs has increased dramatically. As available space for suitable above-ground steel storage tanks became increasingly scarce in Japan, specially designed, lined, underground tanks had to be constructed. Unfortunately, there are no suitable salt deposits in Japan, so the storage tanks must be excavated in hard rock. In other areas of the world where no suitable salt deposits exist (such as Scandinavia), projects have utilized abandoned mine space, excavations in hard rock, and aquifers for storage space.

The United States' dependence on imported oil and the oil embargo of 1973-74 prompted the American government to establish the Strategic Petroleum Reserve (SPR) Program, which was enacted by Congress in 1975 under the Energy Policy and Conservation Act. The SPR is mandated to provide for storage of up to 159 million cubic metres (one billion barrels) of crude oil, in order to reduce America's dependence on imported oil and provide for emergency interruptions in supply.

Figure 3-1 shows the location of North American underground storage sites. Most of the storage caverns are situated in the Gulf Coast region salt domes. There are more than 500 salt domes in the area and salt caverns have been located in the states of Texas, Louisiana, Mississippi, Alabama, and Arizona. Approximately half of the salt domes are located offshore in the Gulf of Mexico, and some of these have been utilized for SPR salt storage caverns.

In Canada, both naturally porous geologic formations and excavated or solution mined cavities have been used for underground storage of various substances. Hydrocarbons, especially dry natural gas, are currently stored in porous sedimentary strata in Alberta, Saskatchewan, and southwestern Ontario as peak shaving operations by gas utilities. Utility companies which distribute natural gas in Canada experience high annual



FIGURE 3-1

NORTH AMERICAN UNDERGROUND STORAGE



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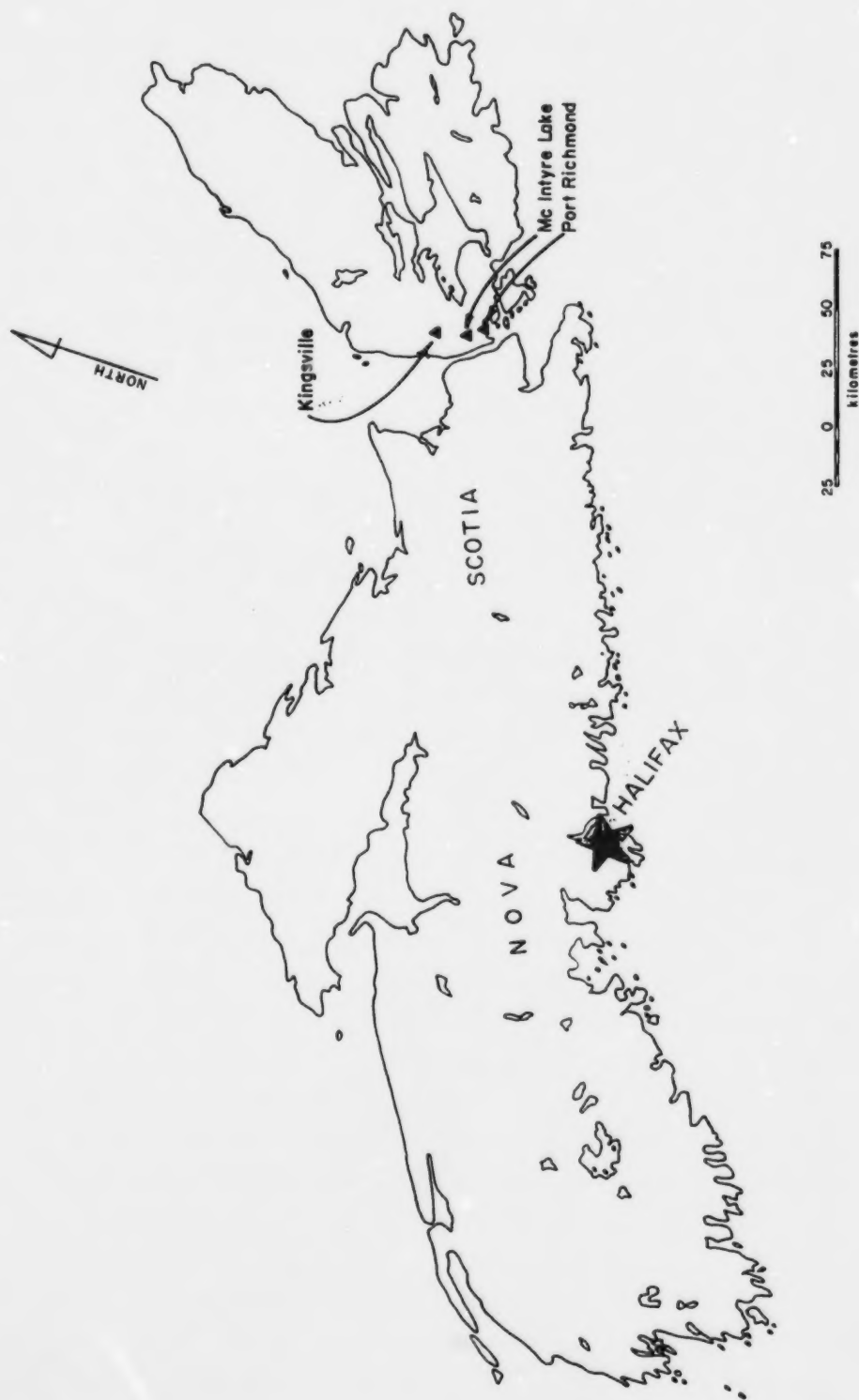
load factors and distribution problems in the peak-supply winter months. Peak shaving is achieved by injecting natural gas into subsurface reservoirs (often depleted gas fields) in the off-peak summer months and withdrawing it during the winter. Approximately 3.5 billion cubic metres of storage capacity currently exists in the Silurian carbonate/evaporite sequence of southwestern Ontario (Simpson, 1977).

Liquefied petroleum gases (LPG) as well as dry natural gas has been stored in salt caverns in east-central Alberta, southern Saskatchewan, and southwestern Ontario over the past 25 years. This method of storage has attained considerable importance relative to other (surface) storage systems, in recent years. The storage caverns in western Canada are at depths of 1000 to 2000 metres in Middle Devonian salt, while those in Ontario are at approximately 500 metres depth in Late Silurian evaporite strata.

Salt caverns are also used as waste repositories in Saskatchewan and southwestern Ontario. Three salt caverns connected to the surface facilities of a chlor-alkali plant in Saskatchewan are used to store mercury compounds. Chlorinated hydrocarbons are stored in a salt cavern in the Sarnia area of southern Ontario. Dow Chemicals' facilities in Sarnia include salt caverns which are used for storage of natural gas and other chemicals and to produce brine which is used as feedstock in the production of chlorine and sodium hydroxide.

Large-scale salt cavern and abandoned mine storage projects have been previously proposed for Atlantic Canada. During the late 1970's, a number of multi-national energy companies carried out cost and feasibility studies for developing hydrocarbon storage caverns in the salt deposits near the Strait of Canso as part of the American SPR program. Various scenarios were proposed involving different combinations of capacities for strategic ("dead") storage and trans-shipment storage caverns. A propane storage project was also proposed for the area, and the potential for utilizing the brine as chemical feedstock from an adjacent chemical plant was considered.

Two test caverns were solution mined at Port Richmond (see Figure 3-2), near the Strait of Canso, by Dow Chemicals in 1975 and 1976. The geology proved to be structurally more complex than originally anticipated,



▲ INDICATES PERTINENT SALT DEPOSITS

FIGURE 3-2

NOVA SCOTIA SALT DEPOSITS PREVIOUSLY ASSESSED

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however, and difficulties with interbedded insoluble rock strata were encountered which caused problems with the brining process. Further work was deferred and the caverns are currently not utilized. The McIntyre Lake salt deposit was also assessed as a potential SPR crude oil storage site by Home Oil et. al. The Kingsville salt deposit was evaluated by Domtar Limited as a possible petroleum storage site. A brining test was conducted which indicated that a cavern could successfully be created by this method.

Elsewhere in Atlantic Canada, the abandoned underground iron ore mines at Wabana on Bell Island in Newfoundland were considered as a potential crude oil storage site by the Wabanex Consortium. A trans-shipment facility was proposed with a capacity in excess of 16 million cubic metres (100 million barrels).



PART B

GEOTECHNICAL CONSIDERATIONS AND EVALUATION CRITERIA

PART B: GEOTECHNICAL CONSIDERATIONS AND EVALUATION CRITERIA

4.0 GEOLOGY OF SALT IN NOVA SCOTIA

Salt (halite) deposits in Nova Scotia are largely restricted to the Lower Carboniferous Windsor Group. The Windsor Group comprises interbedded marine and non-marine sediments which were deposited in a structurally complex subsiding basin generally known as the Magdalen or Fundy Basin. The Windsor Group ranges in thickness up to 1000 metres and perhaps more in deeper parts of the basin where subsurface data is unavailable. An excellent description of the geology of salt occurrences in Nova Scotia and an extensive compilation of available data on individual occurrences and deposits is provided in Boehner's report entitled, "Salt and Potash Resources in Nova Scotia" (1986). The format used in Boehner's report whereby the salt occurrences are listed and grouped by geographical areas is followed in this report. A brief summary of the pertinent characteristics of salt geology in Nova Scotia is provided below.

The Lower Carboniferous Windsor Group is widely distributed throughout Atlantic Canada. It is the only major marine sequence within the Carboniferous section in the region. More than 50 percent of the Windsor Group consists of evaporites (anhydrite, gypsum, and halite with lesser amounts of sylvite). These minerals were precipitated from saturated seawater in a marine basin with alternating regressive/transgressive phases and restricted circulation conditions. The evaporites occur in beds of variable thickness (a few centimetres to tens of metres) and are rhythmically alternating and frequently interbedded with fossiliferous marine limestone and dolostone and reddish and green coloured clastic sediments (siltstone, sandstone, and conglomerate - Boehner, 1986).

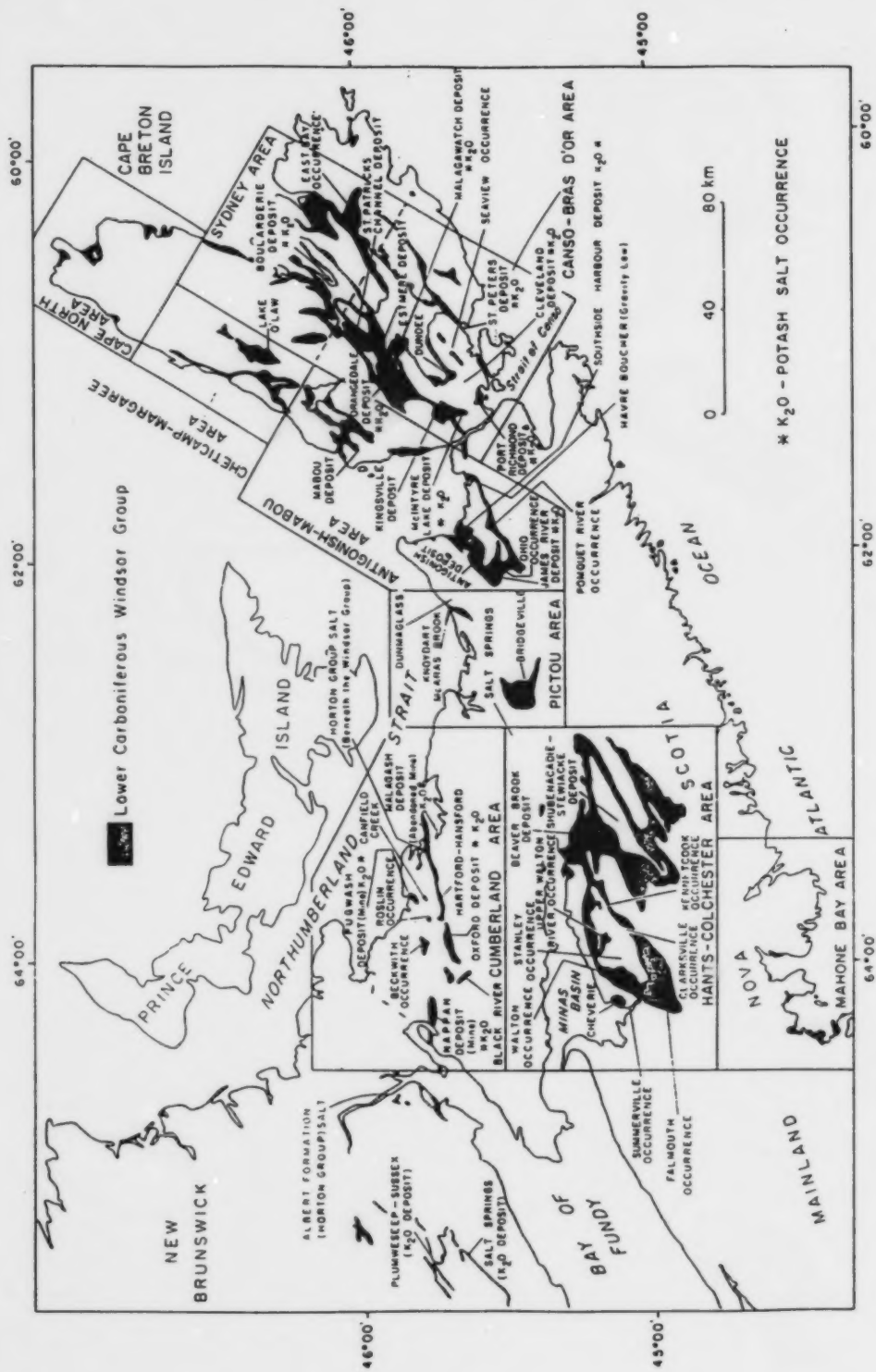
The Windsor Group is underlain by a thick succession of terrestrial clastic rocks belonging to the Lower Carboniferous Horton Group. Rocks as old as Middle to Late Devonian have also been assigned to this Group (Howie and Barss, 1975). These sediments were deposited in subsiding areas adjacent to and overlying older deformed basement rocks dating from the Precambrian to Middle Devonian. Very minor evaporite strata (including halite) have been identified within the Horton Group.

A thick sequence (up to 5000 metres locally) of Upper Carboniferous non-marine sediments overlies the Windsor Group and exhibit both conformable and unconformable contacts with it. These sediments consist mostly of sandstone, siltstone, shale and conglomerate. The clastic sedimentary sequence has been divided into the following Groups (from oldest to youngest): Canso, Riversdale, Cumberland, and Pictou.

Outcrops of the Windsor Group are largely restricted to central Nova Scotia and the northern half of the province, including Cape Breton Island. Figure 4-1 shows the distribution of Windsor Group bedrock and the various known salt deposits, grouped into nine geographical areas. Five of these nine areas have known salt occurrences; namely, Hants-Colchester, Cumberland, Antigonish-Mabou, Canso-Bras d'Or, and Sydney areas. Salt may be present in the other areas underlain by Windsor Group bedrock, but this has not been established by drilling to date.

The salt deposits and associated Windsor Group strata of Nova Scotia exhibit a broad range of structural and stratigraphic complexity. The stratigraphy of salt and potash within the Windsor Group was not well understood until the mid-1970's when deep drilling by mineral exploration companies provided data on the deeper units of the Windsor Group within the Hants-Colchester area. A considerable amount of deep drilling was carried out in the Shubenacadie and Musquodoboit Basins and subsequent detailed stratigraphic studies were undertaken by Giles and Boehner (1979 and 1982 a & b). A classification scheme evolved from these studies whereby five major stratigraphic cycles were identified (Figure 4-2). A three-cycle system, originally described by Giles (1978), was applied to the Shubenacadie and Musquodoboit Basins by Boehner (1984). Giles later refined and expanded the system to five cycles and applied the classification system to the Windsor Group throughout Nova Scotia (Giles, 1981b).

The major cycle classification system (Figure 4-2) is based on lithostratigraphic, and both macro and micro-paleontologic boundaries at the base of each cycle. The various cycles represent major transgressive-regressive phases within the Windsor Group. A brief description of each of the five major cycles is summarized below from Boehner's (1986) report.



Source: Boehner 1986



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FIGURE 4-1
WINDSOR GROUP OUTCROP
DISTRIBUTION AND SALT OCCURRENCES
IN NOVA SCOTIA

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March 1988

Figure 4-3 shows the location of each of the major cycle sections identified in Figure 4-2.

(i) Major Cycle 1

This depositional phase is interpreted as a rapid marine transgression (seawater invasion of a large land area) of a pre-existing subsea level continental basin. It consists of a classic vertical succession of marine carbonates and evaporites ranging up to halite. The major salt section of the Shubenacadie Basin is a part of Major Cycle 1. This cycle may be up to 500 metres in thickness and comprises a laminated basal carbonate, a thick massive to stratified anhydrite, and stratified halite within minor siltstone and anhydrite. Major Cycle 1 contains the economic potash deposits in New Brunswick and has been the target of potash exploration in Nova Scotia as well, but has met with limited success to date. The halite facies of Major Cycle 1 is limited to the Shubenacadie Basin.

(ii) Major Cycle 2

Major Cycle 2 is more widespread than Major Cycle 1. It consists of repeated mini-cycles of transgressive-regressive cycles, comprising marine carbonates, continental beds with a variable, but generally slightly greater amount of evaporites, including anhydrite and minor halite. The interbedded, stratified halite and anhydrite horizons rarely exceed thicknesses of more than 15 metres in the Shubenacadie Basin, but thicker and more abundant halite beds have been found in highly deformed sections of the Canso-Bras d'Or area (Dekker, 1982 and Giles, 1981a).

Potash in uneconomic quantities has been discovered in Major Cycle 2 at McIntyre Lake, Malagawatch, and Orangedale. The halite in Major Cycle 2 at Malagawatch is up to three times the thickness found in the Hants-Colchester area (Boehner, 1983). Major Cycle 2 is interpreted to have been deposited in a subaqueous marine to sabkha-type environment.

(iii) Major Cycles 3, 4, and 5

Major Cycles 3, 4, and 5 are geographically more widespread than Major Cycles 1 and 2. In the Shubenacadie and Musquodoboit Basins, Major

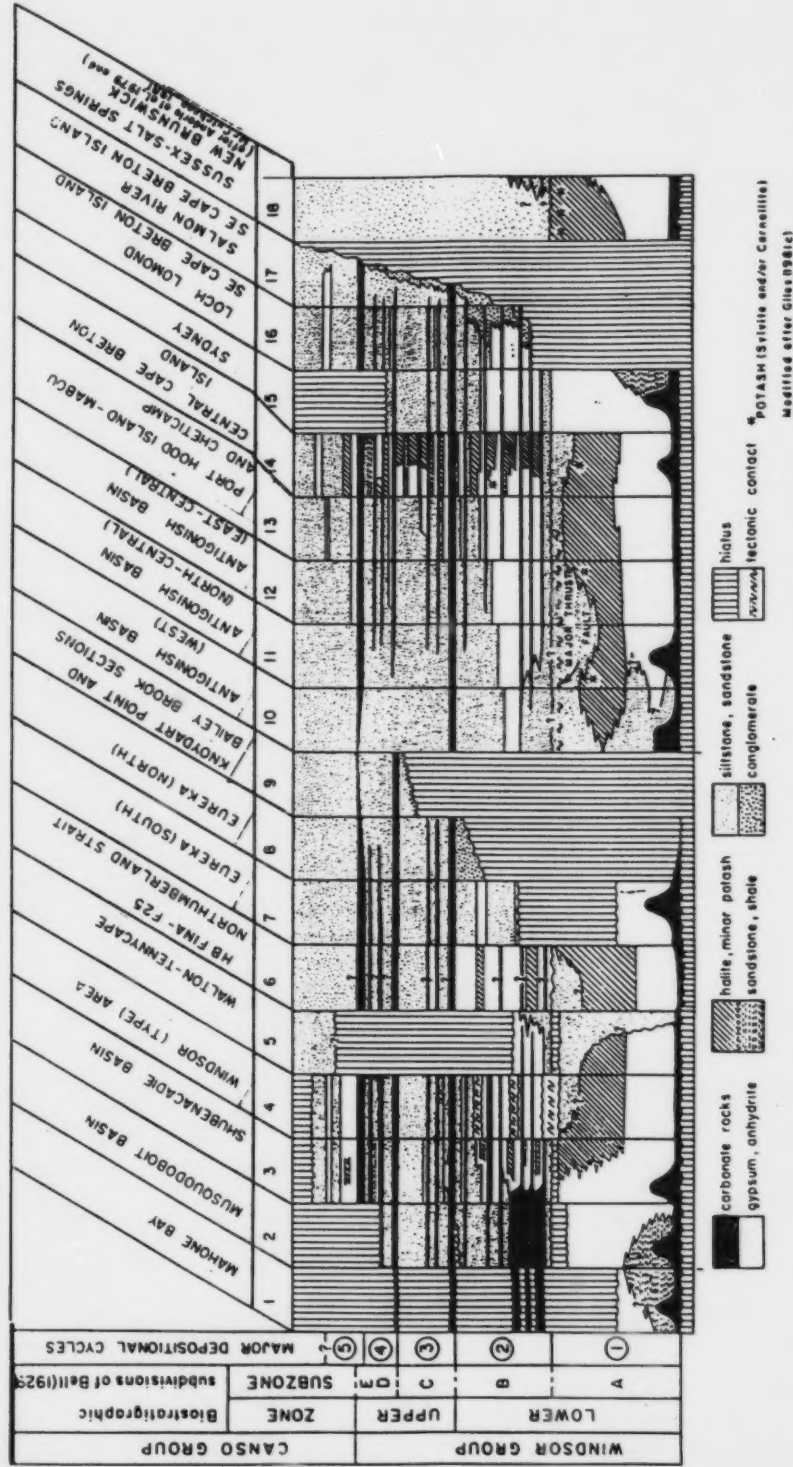
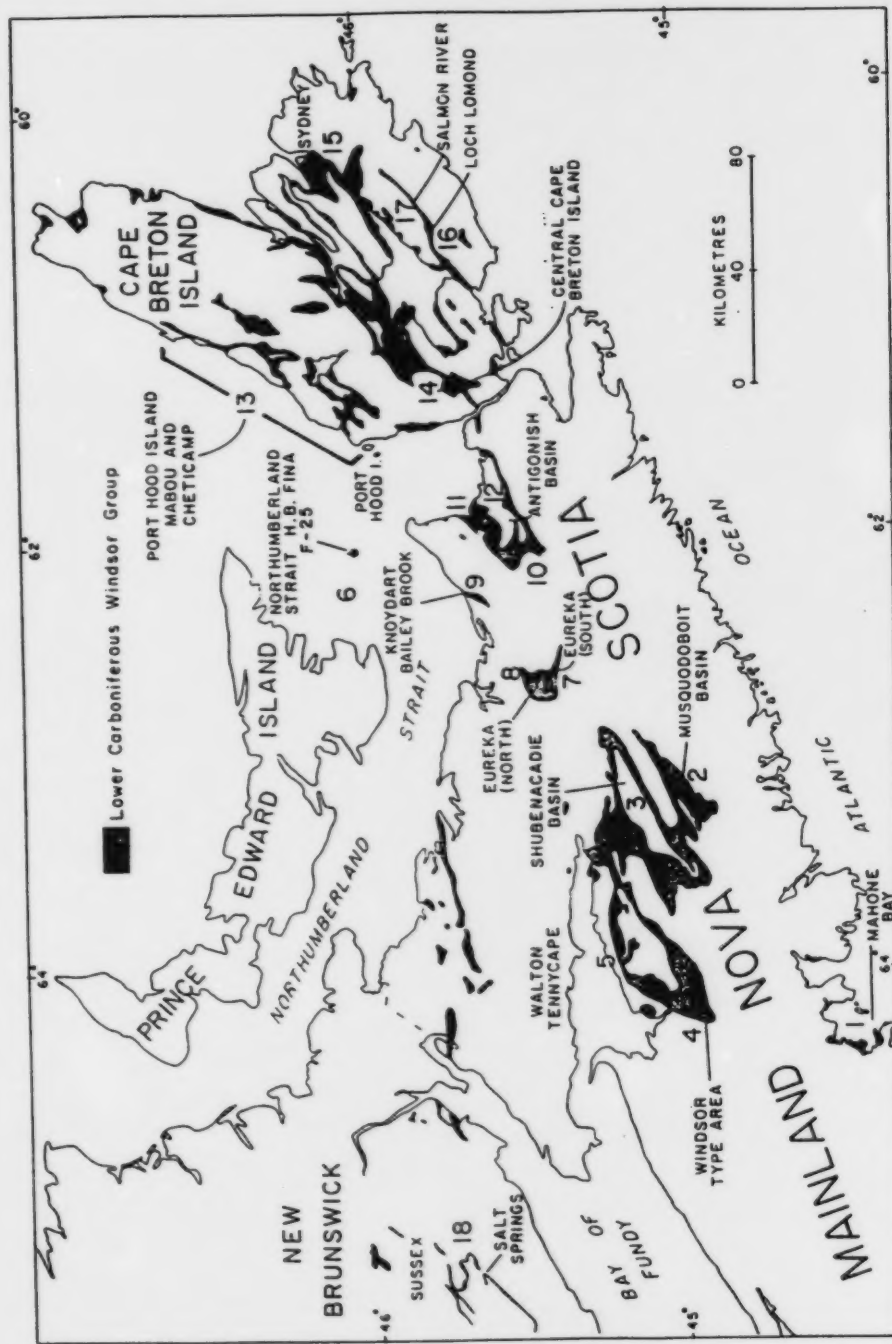


FIGURE 4-2
LITHOSTRATIGRAPHY AND MAJOR CYCLES
OF THE WINDSOR GROUP IN NOVA SCOTIA

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Source: Boehner 1986



Source: Boehner 1986



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FIGURE 4-3

LOCATION OF MAJOR CYCLE SECTIONS

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Cycles 3, 4, and 5 unconformably overlies Major Cycle 2. These three Major Cycles comprise up to nine mini-cycles and differ from Major Cycle 2 mainly in the proportion of evaporites present in the section (less than 30 percent in Cycles 3, 4, and 5).

The highest Windsor Group marine carbonate and the transitional evaporites (anhydrite and halite) which are locally present at the base of the Canso Group, occur within Major Cycle 5. Halite is known within Major Cycle 5 only in the Shubenacadie Basin. However, it is a substantial component of Major Cycles 3 and 4 in the Canso-Bras d'Or area.

The depositional environment of Major Cycles 2 to 5 and transition to overlying strata (Canso Group) must have been dramatically different from Major Cycle 1 (with its single, progressive evaporite sequence). Boehner (1979) attributes the contrast to basin infilling and levelling of the sequence by the thick evaporites of Major Cycle 1. The resulting gentle topography favours shallow water and diagenetic evaporite deposition during regressive phases following cyclic marine transgressions.

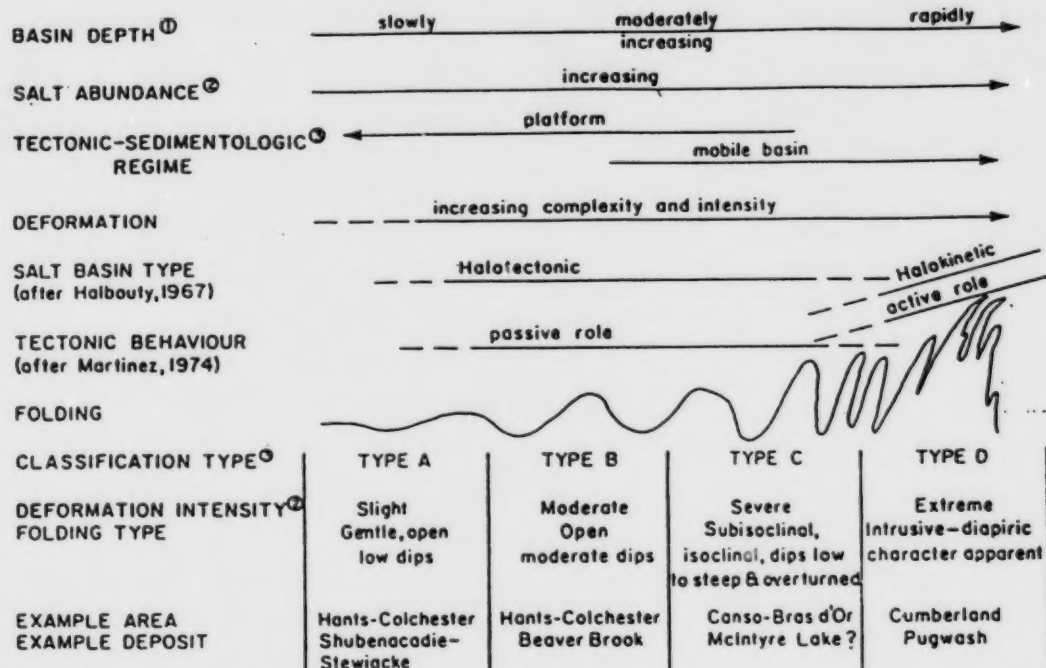
The Windsor Group evaporites of Nova Scotia occur within a broad range of structural settings. The variable degrees of intensity of deformation result from the relative location of the various salt deposits within the depositional basin and the specific tectonic events and the geologic history of the various areas. The major period of deformation in the Magdalen Basin and adjacent areas took place between Early Westphalian and Late Triassic time (Keppie, 1982a). This period of deformation is attributed to movement along the Minas Geofracture, which is the major structural lineation which runs east-west from Minas Basin to Chedabucto Bay and separates the northern half of Nova Scotia from the southern half, both areas having widely different geologic histories.

Two main tectonic settings were present during Carboniferous deposition in the region. One was stable platforms (i.e. the Nova Scotia and New Brunswick platforms) and the other was an intervening fragmented pull-apart basin known as the Magdalen Basin (Keppie, 1982b). Deformation within the Magdalen Basin was most intense along its margins and was accompanied by diapiric structures in specific locations such as the Cumberland area. The variable structural characteristics of the different salt deposits range from, large wall and plug-like diapirs (gravity slide

features) to relatively undisturbed horizontal beds. The most severe deformation is characterized by tortuous folding and isoclinal recumbent to upright orientations, normal and reverse faulting, gravity sliding, and extensive plastic flow features of the evaporite beds.

Figure 4-4 shows Boehner's (1986) classification system for the four main structural types of salt deposits in the province. The structural complexity varies from the relatively undisturbed Type A - for example, the Shubenacadie-Stewiacke deposit which is characterized by very gentle folds with low dips - to the severely deformed Type D - for example, the Pugwash deposit. The structural complexity is generally related to proximity to major faults, intensity of tectonism, and the volume and burial depth of the salt present.

Figure 4-5 shows the geographic distribution of the various structural types of salt deposits. The relatively undisturbed deposits (Types A and B) occur in the basin-shaped fold system located on the margins of faulted (mobile) areas. The structurally complex halotectonic deposits, which were subjected to compressive tectonic forces, are found in the Canso-Bras d'Or areas. The intensely deformed deposits (Type D) are found within the Cumberland area. Here, the evaporite beds occur as wall and dome, diapiric, anticlinal intrusions. These intrusive structures are apparently restricted to areas of thick Carboniferous strata and may be present in the Mabou and Canso-Bras d'Or areas. More subsurface (drill) data is required to confirm this.



① reflects potential geostatic loading influence.

② evaporite tectonics are complicated by heterogeneous lithology, facies variation and uneven distribution of salt in the Windsor Group.

③ any type may occur in simple or complex graben or half graben basins.

Source: Boehner 1986

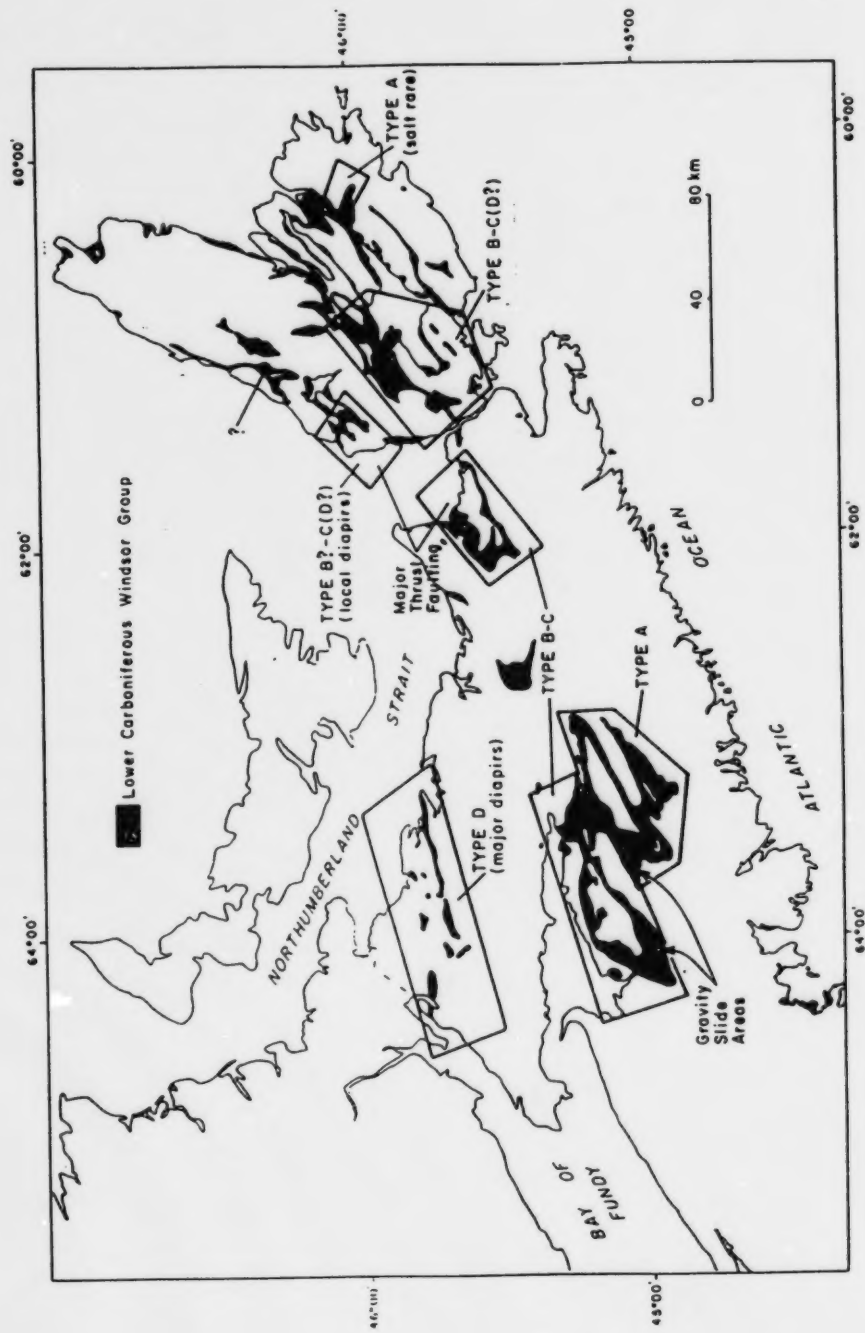


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**FIGURE 4-4
EVAPORITE DEPOSIT
STRUCTURAL CLASSIFICATION**

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Source: Boehner 1986



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**FIGURE 4-5
DISTRIBUTION OF SALT DEPOSIT
STRUCTURAL TYPES**

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5.0 DESIGN OF UNDERGROUND STORAGE IN SALT

5.1 General

This section describes briefly the basic requirements and design parameters (including development techniques, operation techniques, advantages, and cost) for underground storage in solution-mined salt caverns. The information included herein represents guidelines only and will need to be revised to suit site and project-specific requirements.

Determination of optimal cavern size and number, and development schedule and costs is not possible without previous determination of economic, structural, commercial, environmental, and operational criteria.

5.2 Basic Requirements

The following conditions are necessary to develop solution mined storage caverns in salt:

1. a sufficient thickness of structurally competent salt at a proper depth, without an excess of interbedded insoluble rock materials;
2. an adequate supply of fresh (or low salinity) water; and
3. an environmentally acceptable and economical means of disposing of the resultant brine.

5.3 Cavern Design

5.3.1 Basic Criteria

The basic criteria to be established as a framework for design development are that the design will:

1. provide a cavern that is structurally sound (based on rock mechanics evaluation);
2. support standard well construction; and
3. allow the performance of the required leach or leach/fill schedule.

The subsurface portion of the design comprises the determination of cavern size, geometrical configuration, location within the salt, well completion and hydraulics, and the development of a leach or leach/fill concept of cavern creation. The cavern creation concept should provide the various site storage capacities necessary to meet the given schedule and function criteria.

The primary concerns in developing cavern design parameters are the structural stability and pressure tightness of the caverns. The limitations of the salt deposit and the efficient use of available area are other factors which indirectly affect cavern size, but primarily affect cavern locations.

In comparison to other rock types, salt is an ideal material for storage of liquid and gaseous hydrocarbons, petrochemical products, compressed air, and hazardous wastes. This is primarily due to the economics of mining the cavern opening in salt. However, to maintain proper cavern stability and pressure tightness, a sufficient amount of salt is required to be left in place surrounding a cavern. Loss of pressure integrity is often caused by improperly cemented or deteriorated cavern walls. Nevertheless, geologic features, such as interbedded anhydrite, shale stringers, potash inclusions, faults, fractures and porous zones may also be the cause of leaks in caverns. The possibility of detrimental effects of such features, where present, is mitigated by having sufficient salt surrounding the cavern.

The mechanical behaviour of salt, which in geological terms is described as very plastic, means that it will undergo creep or permanent deformation at relatively low stresses. This behaviour is a benefit to the design of storage caverns, in that it allows the redistribution of stresses and the "healing" of any fractures that occur as a result of creating an underground opening in a rock mass. However, the need to insure an adequate thickness of salt around the cavern relative to the cavern size, in order to redistribute stresses does place some restrictions on cavern location and spacing.

Variation in the magnitude of the pressure inside a cavern and the rate of pressure variation can compromise the cavern's structural stability. The geostatic stresses are normally partly balanced by the hydraulic pressure in the material stored in the cavern. Reducing this cavern internal pressure will increase the salt creep rate by increasing the pressure difference; increasing the cavern internal pressure beyond pre-established limits may fracture the salt or otherwise damage the last cemented casing shoe; a high rate of reducing or increasing the cavern

internal pressure may stress the surrounding salt quickly enough to make it behave as a brittle material, with potentially severe sloughing/collapse and tubing damage.

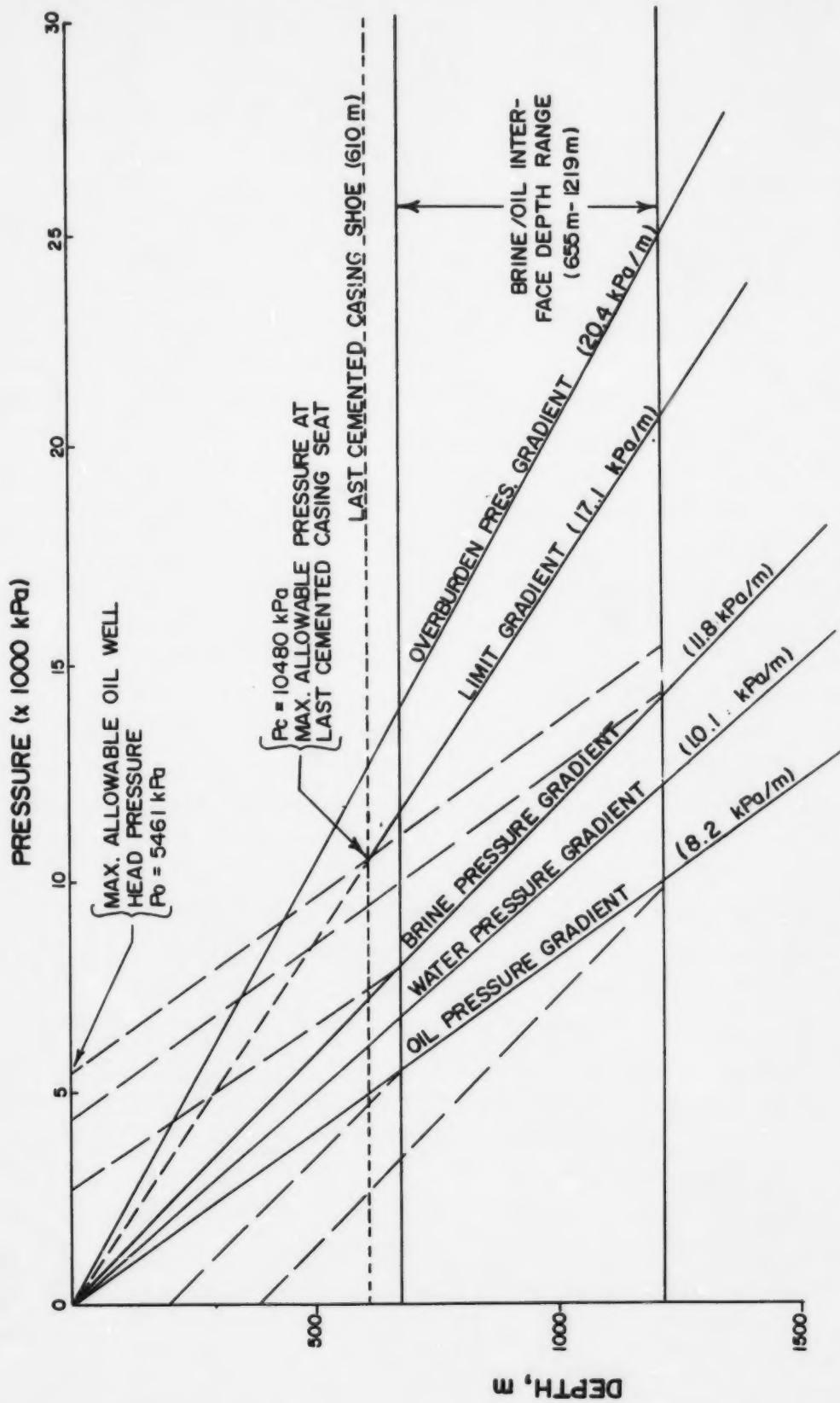
As the cavern depth below the ground surface increases, the differential stress experienced by the cavern walls increases. This will cause the salt to undergo increased plastic deformation or "creep". The exact magnitude of this deformation and the related volume loss in the cavern are dependent on site-specific characteristics and cannot be accurately predicted. Even with extensive exploration and testing of salt samples, predictions of creep closure will exhibit high uncertainty because of the relative difficulty of testing salt behaviour in the laboratory and extrapolating the data to in situ behaviour. Due to the increased creep closure rate experienced at greater depths, the current practice is to limit storage cavern depths to about 1800 m (6000 feet).

A greater cavern height allows a larger possible storage volume to be created within a given area. Appendix A contains calculations which demonstrate that the total storage volume possible within a given surface area, complying with any reasonable spacing requirement, is essentially independent of the cavern diameter. The controlling factor in storage volume which can be created is, therefore, the cavern height.

5.3.2 Cavern Pressure Limitations

5.3.2.1 Cavern and Wellhead Pressure Conditions

During cavern development, a light substance is used as a blanket (to prevent upward dissolution of salt, see Section 5.4.4) and brine and blanket fluid will always co-exist in the cavern, regardless of the development strategy used. The cavern internal pressure is that resulting from the hydrostatic head of the fluids inside the cavern. It depends upon the specific gravity of the fluids involved and the depth of the fluid interface between the brine and the blanket substances. At the interface depth, the blanket pressure is equal to the brine pressure. The brine pressure is the hydrostatic head to the ground surface plus a small, excess pressure which is the pressure in the line to the brine pond. Due to its lower density in regard to brine, the blanket fluid is under a higher pressure than just the static head to the surface. Figure 5-1 illustrates



the pressure distribution in wells and caverns for an oil blanket and brine system under static conditions.

5.3.2.2 Allowable Range of Cavern Pressure

The upper limit of the allowable range of cavern pressure is dictated by the overburden pressure. In the design criteria (Level III) for the US Strategic Petroleum Reserve Facilities (April 1981), the maximum allowable wellhead pressure is such that will result in a maximum pressure gradient at the last cemented casing shoe of 83 percent of the established lithostatic overburden pressure established for the site. In the absence of site data, the overburden pressure is limited to 20.4 kPa/m (0.9 psi/ft.) of depth. In the case of multiple well caverns, the maximum operating gradient is to be assessed against the shallowest, last cemented casing in the same cavern.

In contrast to the maximum allowable cavern pressure, there is no generally accepted rule for estimating the lower limit of the allowable range of cavern pressure. The minimum allowable cavern pressure is influenced by the need to minimize the differential between the geostatic and cavern pressures. Normally, a limit is defined as the minimum pressure at which no short-term failure is to be expected and the cavern volume losses due to creep remain within an acceptable range. The minimum allowable cavern pressure is, therefore, dependent on the type of substance being stored and on the type of operation established for the facility.

If the operation requires full cavern depressurization (atmospheric cavern pressure) then the storage should not be constructed at depths greater than 1,000 m (3,300 feet). Caverns located deeper will require a minimum pressure to be maintained at all times. The pressure resulting from a full column of blanket fluid to the surface, which corresponds to atmospheric wellhead pressure (zero kilopascals on the blanket wellhead side) will usually be the lowest operating pressure. This condition is experienced during work-overs performed during the cavern development and operating periods.

In the case of pressurized storage (such as natural gas) the maximum and minimum pressures are the leading parameters determining the storage capability of the caverns and the storage cost per unit volume.

5.3.3 Cavern Size

The following factors are to be considered in selecting the cavern size:

1. geologic constraints: salt structure, orientation of strata, distribution of insoluble layers, predicted confidence levels in data;
2. the state-of-the-art of leaching and cavern design technology;
3. regulations concerning the spacing of caverns;
4. past experience and existing site designs;
5. brine concentration for efficient operation;
6. the effects of cavern growth due to cycling;
7. leaching and withdrawal hydraulics; and
8. the efficient utilization of the natural resources constituted by the storage space.

Due to the process of cavern creation through solution mining, and to the plastic deformation of the salt rock, consideration has also to be given to the need to allow for sufficient extra volume to accommodate:

1. the volume of insoluble non-salt materials in the salt rock which drop to the cavern bottom during cavern creation and subsequent enlargement (this spacing has to be created in advance and will finally be filled up and no longer represent storage space); and
2. cavern creep compensation, and for safety in regard to predetermination of the lowest blanket/brine interface depth.

Selecting an "optimal" cavern size, considering all the controlling factors and possible delays which could affect the "optimization" of the cavern size, is an extremely site (and project)-specific task. Only for a particular site and for a specific set of operational criteria and schedules, will it be possible to optimize cavern size.

The purpose of this study is not to optimize cavern size nor to determine a size to be utilized in detailed design. It is, however, pertinent to establish a rough estimate for a suitable cavern size to allow considerations in scheduling and budgeting. A 950,000 m³ (6 million

barrels) cavern is considered a reasonable cavern size which should provide good structural stability at a low unit cost. In general, larger caverns provide lower storage cost per unit volume (specific storage cost).

5.3.4 Cavern Height

Recognizing that the controlling factor over storage volume creation within a given area is the cavern height (see Appendix A), it is, therefore, desirable to maximize the cavern height for a given facility. An increased cavern height offers three basic advantages over shorter designs:

1. increased thickness of salt between caverns (for the same storage volume) allowing greater structural stability and reduced sensitivity to irregularities during leaching;
2. increased initial brine salinities due to the increased area of contact between water and salt rock; and
3. more efficient use of the salt deposit (i.e. minimizes the areal extent of resource utilization).

Based upon experience with oil storage caverns, 600 m (2,000 feet) is usually the maximum practicable cavern height.

5.3.5 Cavern Shape

When designing cavern shape, the following major topics must be considered:

1. Stability (including optimizing structural configuration and available salt thickness);
2. Storage Substance;
3. Product Cycling; and
4. Leach/Fill Procedure.

Regarding stability, it is generally desirable to produce caverns with diameters less than their height. This subject is extremely application dependent and not yet considered fully quantifiable. The relations between the cavern diameter and the thickness of salt in between caverns and overlying the cavern roof, herein called stability parameters, will be discussed in Section 5.3.6, "Cavern Spacing."

The storage substance must be considered since its specific gravity will determine the differential pressure between cavern and formation pressure. Theoretically, filling the cavern with a substance matching the density of salt will produce no structural stresses.

Product cycling with raw water affects cavern volume and shape. It is common practice to design the caverns for ultimate enlargement which will occur after fill/withdrawal cycles with raw water. The ultimate cavern capacity determines the cavern shape and spacing. The initial shape must, therefore, be designed so that stability is still maintained after cycling.

As an example, the SPR caverns in the US Gulf Coast area were typically designed for five fill/withdrawal cycles with raw water. Computer simulations show that a flower pot initial shape is required to achieve a final cylindrical shape for the caverns after five cycles (see Figure 5-2). The figure also illustrates the maximum cavern diameters that are obtained after five storage cycles with raw water for caverns 300 metres (1,000 ft.), 450 metres (1,500 ft.), and 600 metres (2,000 ft.) high.

5.3.6 Cavern Spacing

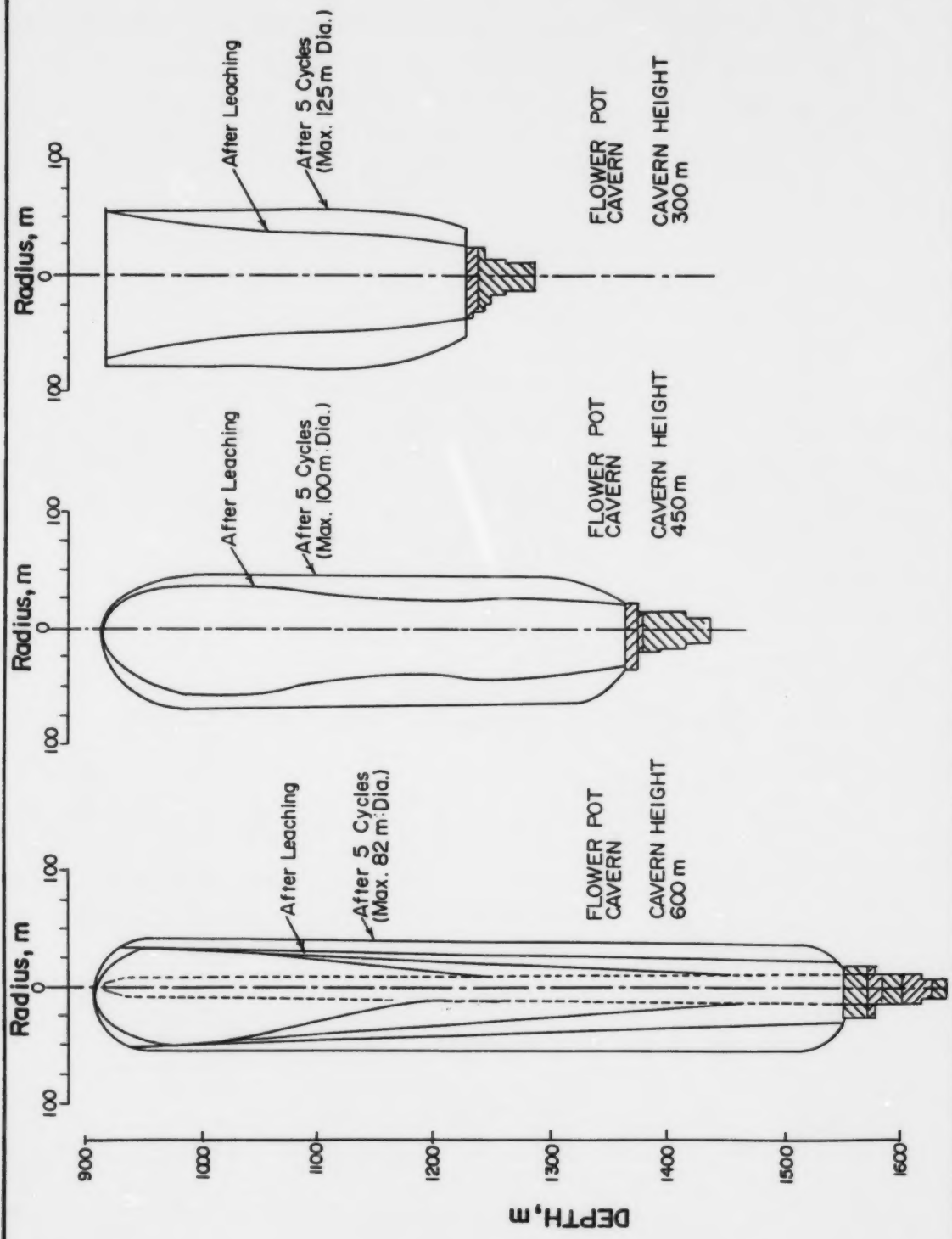
Concerning the problem of cavern spacing, the following factors* must be considered:

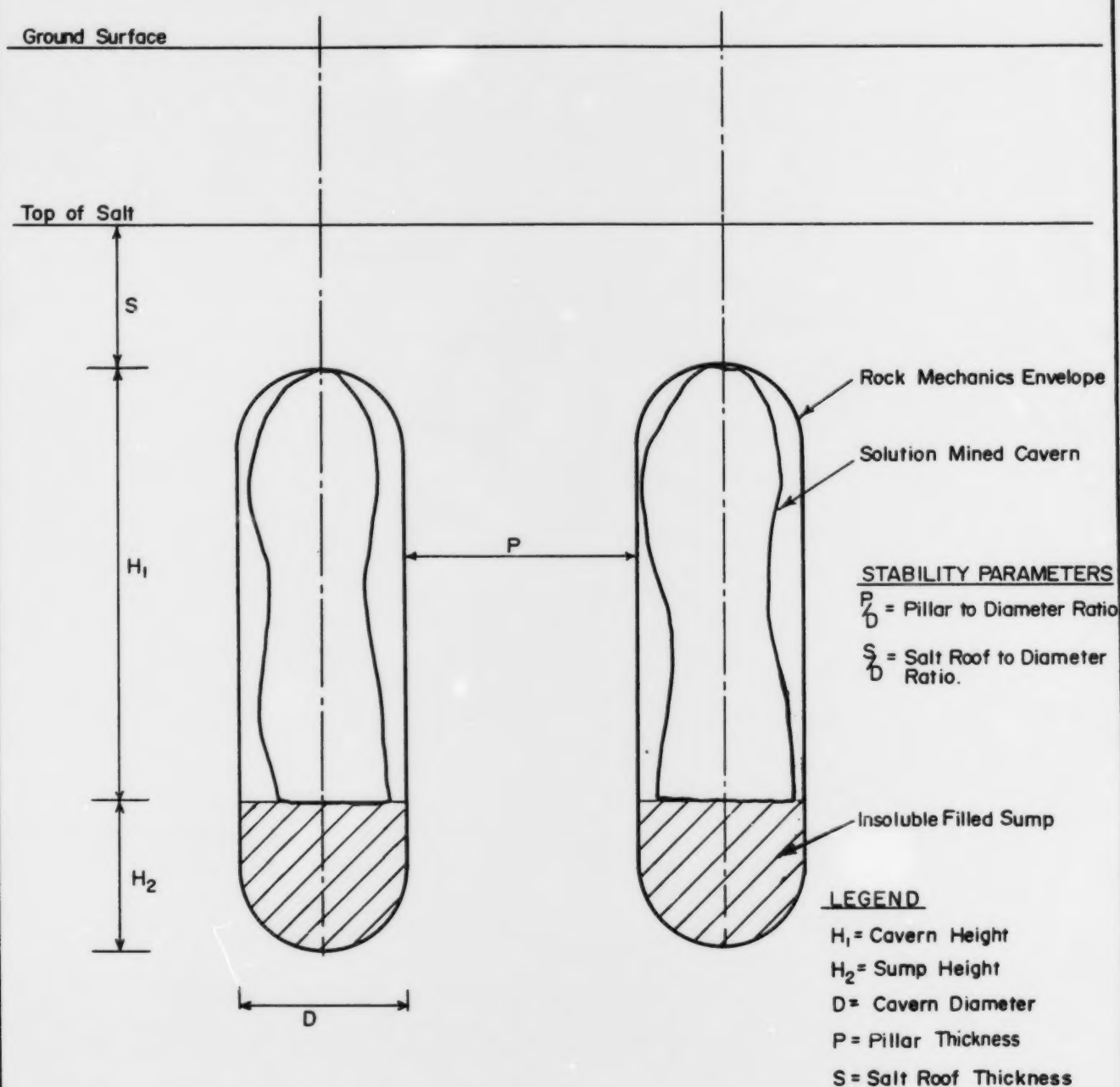
1. structurally stable storage caverns require a pillar to diameter (P/D) ratio of at least 2.0 (this can vary depending on density of the storage substance);
2. structurally stable storage caverns require a salt roof thickness to diameter (S/D) ratio of at least 2.0;
3. the volume of individual caverns of the same height does not significantly affect the total storage volume which can be constructed within a certain property area based on the requirements listed in 1. and 2. above (see Appendix A);

*Except for the stability parameters, P/D and S/D, all the other factors have already been discussed in the preceding paragraphs. The P/D and S/D parameters are defined in Figures 5-3 and 5-4.

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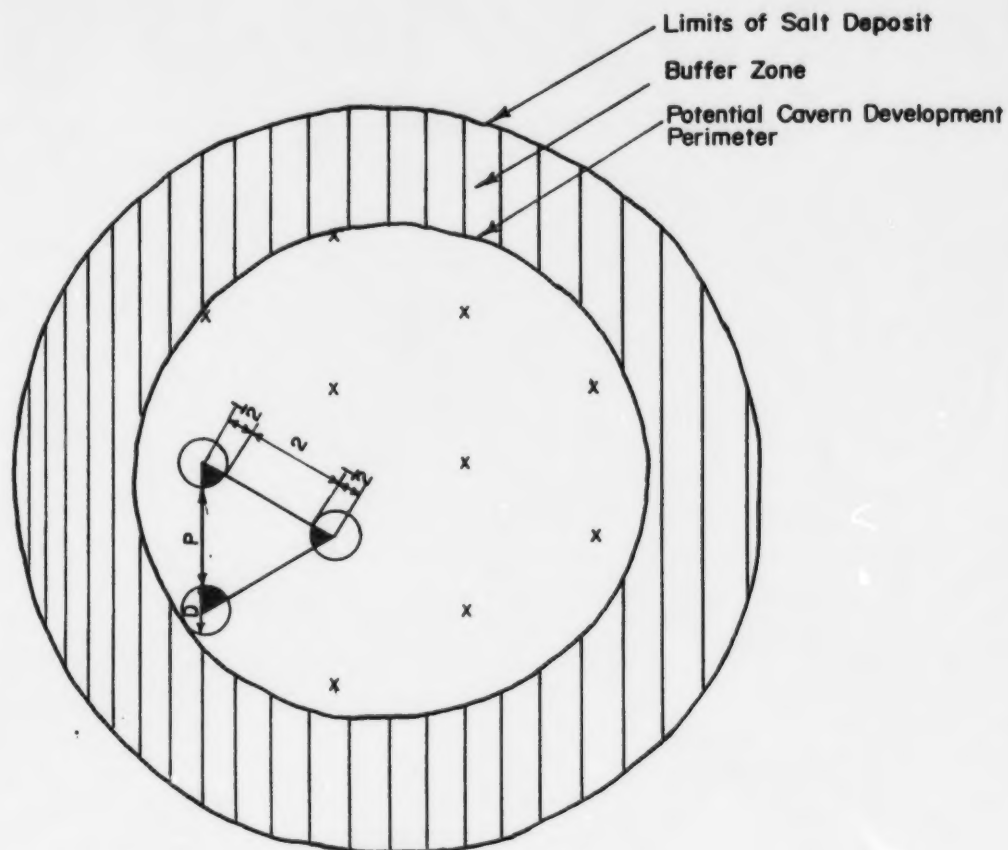
FIGURE 5-2
MAXIMUM CAVERN DIAMETERS





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**FIGURE 5-3
STABILITY PARAMETERS**



x = Cavern Location (centre)

P = Pillar Distance

D = Cavern Diameter

For $\alpha = 60^\circ$

$$\frac{P}{D} = 2$$

$$\text{Area } \Delta = \frac{3}{2} \times 2.60$$

$$= 3.9$$

Area of sector, Δ ;

$$= 3 \times \frac{60}{360} \left(\pi \frac{1^2}{2} \right)$$

$$= 0.131$$

∴ Ratio of % useful area to total

$$= \frac{0.131 \times 3}{3.9} = 0.1007 \text{ or } 10\%$$



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FIGURE 5-4

PLAN VIEW OF CAVERN LAYOUT

4. taller caverns allow more storage capacity to be constructed within a given area, while complying with the requirements given in 1. and 2. above;
5. the leaching design for a 600 m (2,000 ft.) high cavern has been confirmed during the construction of the US and West Germany petroleum reserve storage caverns; and
6. the base of the caverns should not be below 1,800 m (6,000 ft.) depth, due to high rates of creep closure at such depths.

5.3.7 Well Size and Number

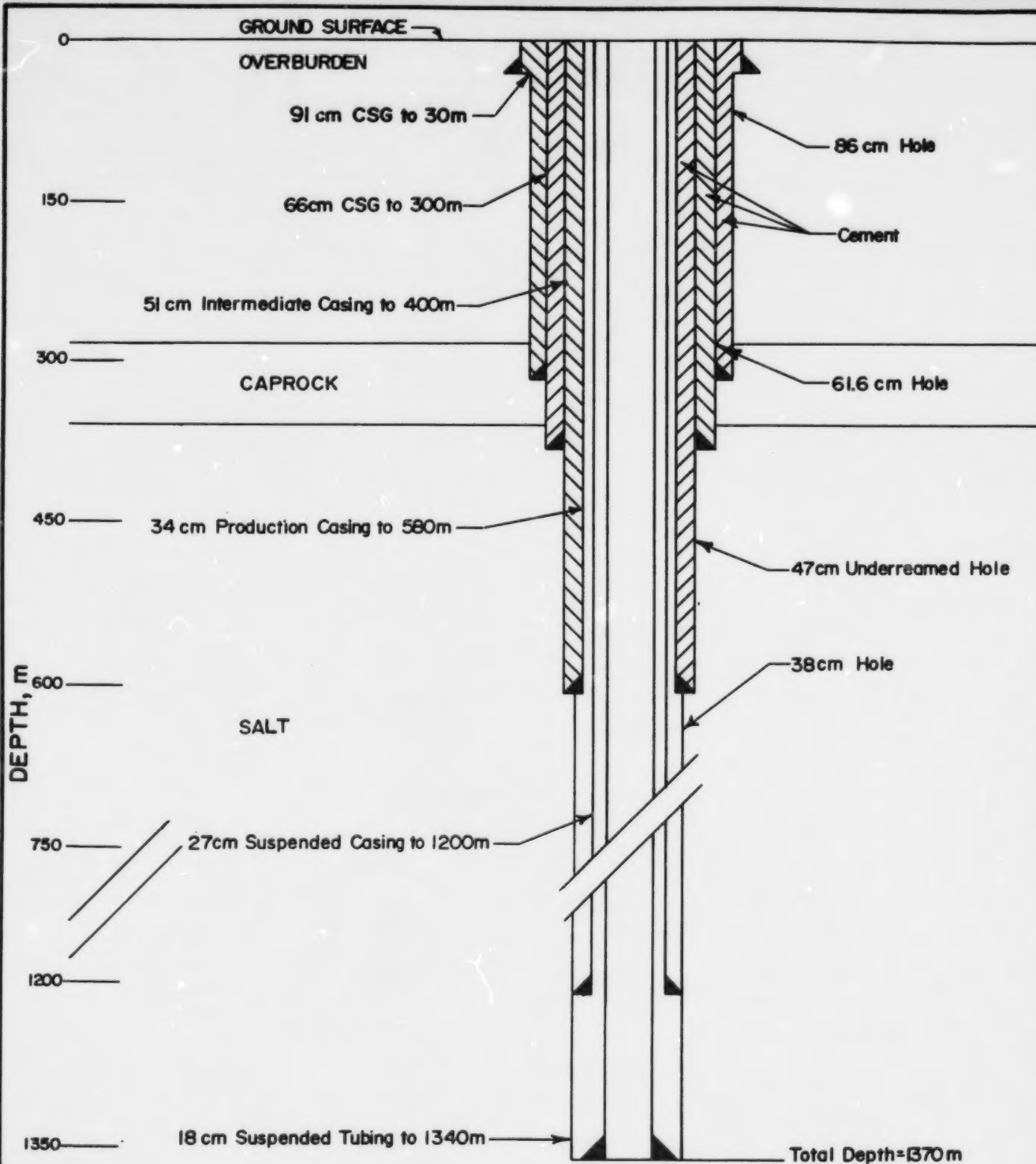
In the design of a cavern well, the operational requirements must first be considered. Flow rates, solution mining schedule, and product movement will determine the selection of the suspended and last cemented casings. The wells used for the solution mining of a cavern are designed to provide protection against the possible pollution of surface water and to insure well integrity throughout the life of the facilities.

The casing programs for each site are designed to meet government regulations and engineering requirements in the most economical manner. Typical US regulations require the installation of at least two cemented casing strings into the salt. The site-specific geological situation will determine the need for additional or optional casing to complete the well along with the required last cemented casing.

The flow cross section of any cavern well completed for leaching or storage operations limits the maximum permissible mass flow rates. If schedule-dictated flow rates exceed the well capacity, then either the well diameter and drilling program must be modified or the number of wells per cavern increased. The maximum permissible mass flow rates are also limited by the pumping capacities and pump pressure which, in turn, are designed for the maximum allowable pressures at the last cemented casing shoe.

Figure 5-5 illustrates a typical well construction for a salt dome.

There is not one optimum well configuration for all sites and all design and operational criteria. As previously stated for cavern size, the configuration of size and number of wells is a very site (and project)-specific task.



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**FIGURE 5-5
TYPICAL WELL CONSTRUCTION
FOR A SALT DOME**

The cost of wells for a given cavern does not increase linearly with cavern volume, since there is only a finite number of practical well sizes. Therefore, as the required flow capacity for a cavern increases, no extra cost is incurred until a new well size or an additional well is required.

5.4 Cavern Development Techniques

5.4.1 General

Several cavern construction techniques are available: single well, multiple-well coalesced cavities, fracture-connected cavities, and recently, cavities connected using the horizontal drilling technique. Selection of the best method of cavern construction depends upon the salt deposit depth, purity, thickness, and the substance to be stored.

Solution-mined storage caverns are constructed by injection of fresh or relatively low salinity water (usually referred to as "raw water") into a salt deposit through one or more wells. The most common industrial practice in salt domes has been to use a single well equipped with two concentric suspended strings of pipe. "Blanket" is injected through the annulus between the cemented casing and the outer suspended string to protect the cavern roof from dissolution (see Section 5.4.4). Raw water and brine are transported through the annulus between the two suspended casings and through the bore of the inner suspended casing.

The leaching steps involved in the development of a storage cavern usually require various adjustments in flow directions and suspended casing setting depths. These adjustments are necessary to control flow and dissolution patterns and produce the desired cavern configuration.

The rate at which the cavern enlarges is dependent on the rate of flow within the cavern and brine concentration, both of which are essentially a function of raw water injection rate, actual cavern volume, contact surface between salt and water, and the method of leaching. Flow pattern efficiency is generally reduced by insoluble layers and resulting wall irregularities. Two basic leaching methods, direct circulation and reverse circulation, are normally used as part of any leaching operation.

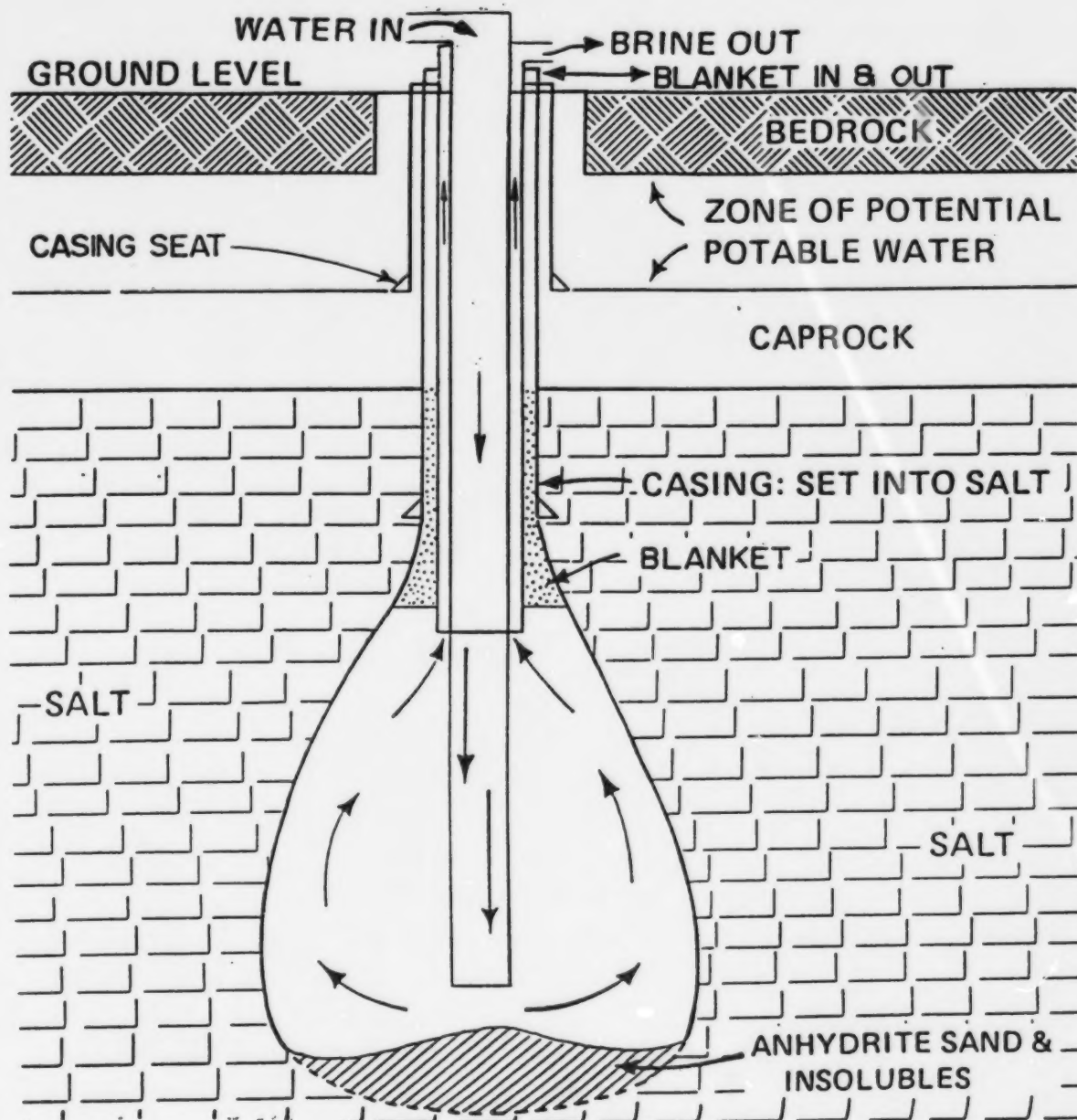
5.4.2 Direct Circulation Leaching

Direct leaching (see Figure 5-6) involves raw water injection through the inner suspended string near the bottom of the cavern, and brine withdrawal through the annulus between the inner and outer casing strings above the raw water injection point. With the direct leaching method, cavern diameter is largest near the bottom of the cavern, and decreases towards the top.

5.4.3 Reverse Circulation Leaching

Reverse leaching (see Figure 5-7) involves raw water injection down the annulus between the inner and outer suspended strings, displacing brine into the inner string below the raw water injection point. During this leaching process, the inner string must always be placed above the residue bed to avoid plugging of the inner casing with the insolubles that may be carried by the brine. The reverse leaching method causes development of larger diameters above the raw water injection point and decreasing diameters toward the brine production point. Cavern configurations resulting from reverse circulation are very sensitive to the positions of the suspended strings within the cavern. By raising or lowering the strings, cavern shapes can be controlled to achieve desired configurations.

The leaching system includes a water source (surface, water well, or sea water); water intake pumps; a water pipeline channeling the water to the leaching site; main pumps to produce the pressure required by the leaching process; a brine pipeline channelling the brine to the disposal site; brine disposal system (water body, deep wells, or commercial processing); blanket tanks and pumps; and all other field piping and manifolds required to handle the water, brine, and blanket flows. Brine filtering may be required in the case of deep disposal wells, and brine dilution may be required in the case of disposal into a body of water. Treatment methods include settling ponds and desliming with flocculants. A brine pond may also be required. Figure 5-8 is a schematic of the leaching process.

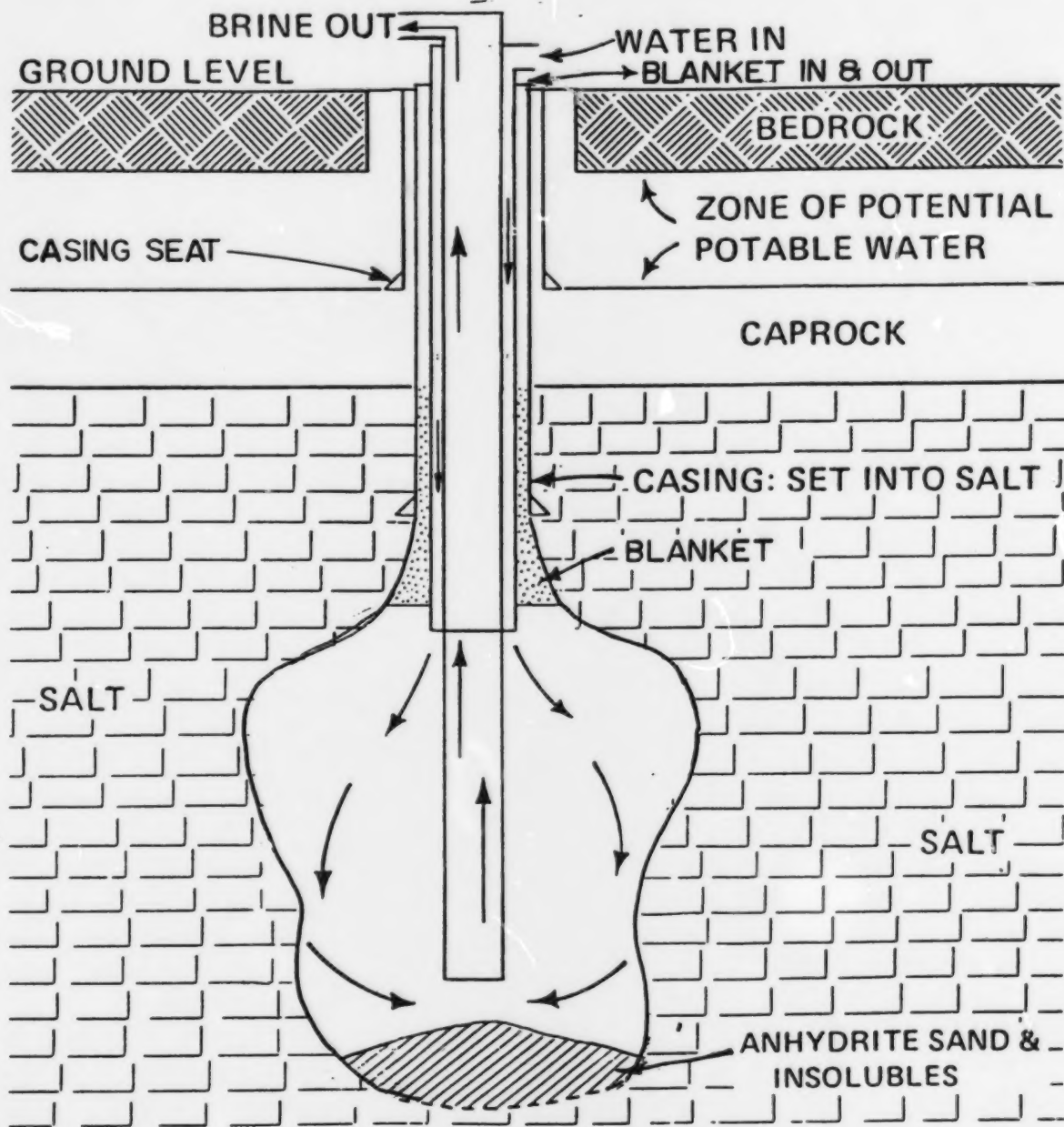


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FIGURE 5-6
DIRECT CIRCULATION

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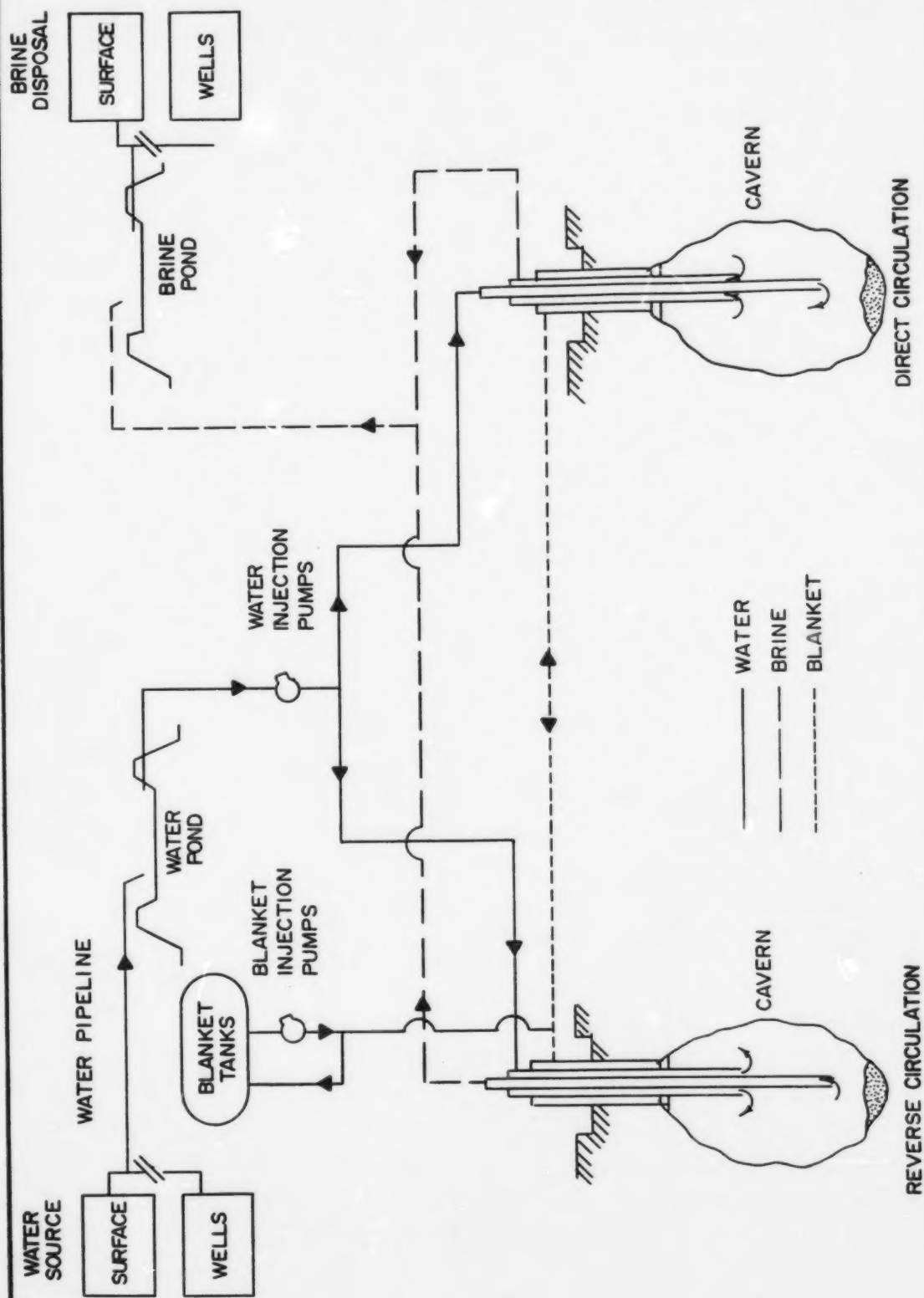


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FIGURE 5-7
REVERSE CIRCULATION

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FIGURE 5-8

LEACHING PROCESS FLOW DIAGRAM

5.4.4 Sump and Blanket Requirements

A sump is initially created to allow for settlement of the insoluble material. Normally, insoluble contents of up to 3 percent of the volume are considered to be the limit for leaching without an extra sump.

Both the direct and reverse leaching methods described above dissolve salt on all of the exposed salt surface. To prevent upward growth of the cavern to a point above the planned cavern top, this region must be protected from leaching. This is done by using a blanket substance, which is any noncorrosive, immiscible substance lighter than water (gas, propane, diesel oil, crude oil, etc.). The blanket prevents leaching of salt from around the last cemented casing and also protects this casing from internal corrosion.

Cavern roof construction and control is of extreme importance. An arched shape is preferable to allow for the redistribution of stresses in the overburden above the cavern. In the roof construction, a protective blanket is used to prevent upward growth and maintain the cavern within the design parameters.

5.4.5 Leaching Simulation

The design of the solution-mining process is normally based on numerical solution mining simulation programs. The exact properties of the salt underlying the sites are not immediately available and predevelopment planning is based upon leaching in homogeneous salt. The content of the insoluble salt material is generally assumed to be 5 percent of the volume for simulation. The salinity of the injected raw water is assumed to be between 0 and 36 grams per litre, which corresponds to the salinity of fresh water and sea water, respectively.

A computer model is used for all phases of actual cavern construction in an ongoing trial-and-error empirical procedure to detect differences between prediction and actual experience. If deviations become critical, new predictions are calculated and modifications to field operations and surveys are suggested. The deviations will be caused by changed geologic conditions or other factors. Evaluation of well logs, core analyses, and the simulation program provide a basis for meaningful operational decisions. Thus, a reliable approach to the leaching operation

is found, including adjustment to geologic deviations from original concepts. Prior to implementing any changes in operational procedures, effects on leaching are predicted with the model.

Some leaching designs are easier to simulate than others. The multiple-well system presents a somewhat more difficult problem. Each of the wells must be modeled separately prior to cavern coalescence. No known simulation program can accurately model the coalescence phase. The design engineer must run a series of independent simulations and approximate the leaching pattern.

5.4.6 Cavern Development Monitoring

Monitoring the cavern development involves daily measurement of flow rates, pressures, and concentration; and periodic downhole geophysical logging and sonar surveys. Sonar surveys and interface logging are compared with production data and computer simulation to predict cavern development. These types of surveys should be carried out quite frequently in the early stages of cavern development.

5.4.7 Leaching Schedules

Commonly, the limiting factor for leaching is the raw water flow rate or the brine disposal rate. The leaching rates of a site, together with the time period for the development of certain storage volume, forms the framework for the design of caverns and surface facilities and of their operational mode. By dividing a given single cavern flow rate into the total allowable brine disposal rate, the number of caverns that can be leached simultaneously is determined.

The schedule for leaching a cavern is predominantly a function of the leaching water injection rate. Therefore, any configuration of wells capable of maintaining a certain leaching rate per cavern, will have similar schedules. Leaching time is estimated from computer simulations of the leaching process.

The number of leaching days are calculated at the maximum leaching rate. In a multi-cavern field, such as the SPR sites, the flow rates per cavern would be varied to maintain the total designed leaching rate when some of the caverns are out of operation due to workovers.

For realistic planning, detailed schedules for leaching must include time increments for extra sump, brine cushion volume, cavern surveys, and system downtime. Realistic schedules vary significantly from site to site and have to reflect time-dependent site conditions.

5.5 Storage Operation Techniques

Depending on the substance being stored and on rock mechanics considerations, several operation techniques can be used. Five techniques are outlined below.

1) Raw Water Displacement

The stored substance is withdrawn by pumping raw water into the cavern. This technique is normally used in low pressure liquid storage such as crude oil and LPG. It is frequently used in salt domes where large cavern sizes can be developed.

2) Brine Displacement

Similar to water displacement, the difference is that no cavern enlargement will result from withdrawing stored substance.

Both techniques above result in a nearly constant cavern pressure and a nearly constant deliverability rate. A displacement string is required in both techniques, which lowers the maximum deliverability for any given well configuration. Brine displacement requires a large brine storage pond. Raw water displacement can permit the placement of a cavern into storage before it reaches mature size and can postpone the requirement of brine pond construction.

3) Pump-Out

This technique involves installation of a submersible pump downhole. Its desirability decreases as the cavern depth increases. No surface brine pond is required and very high withdrawal rates are possible. The technique does, however, limit the roof span that can be developed due to the relatively low cavern pressure involved.

4) Pressure Vessel

The cavern is operated between a maximum and minimum pressure. This technique is commonly employed in gas storage (natural gas and compressed air). In the case of natural gas storage, the minimum pressure limit can either be higher than the cross country pipeline pressure, in which case the gas will flow into the pipeline; or the minimum pressure limit is allowed to drop below the cross country pipeline pressure, in which case the gas will need to be recompressed for distribution.

This technique results in a declining gas withdrawal rate. Gas remaining in the cavern is called cushion gas. Gas withdrawn is called working gas.

5) Evacuation

Complete evacuation of the brine is required in the cases of compressed air storage and hazardous waste disposal. Upon completion of the leaching process, the cavern is fully dewatered, thus remaining under atmospheric pressure until a substance is stored in the cavern.

5.6 Advantages of Subsurface Storage

As a necessary part of implementing the SPR program in the US, Environmental Impact Statements (EIS) were prepared for individual sites, several sites comprising a group, and the project as a whole. Alternate modes of storage were addressed. The EIS shows that the least environmental impact was associated with underground storage in salt domes in comparison to all other surface storage. Disadvantages cited for some specific sites included the necessity for a surface brine pond if this mode of displacement was required and potential difficulties with brine disposal at certain sites.

The following additional advantages are associated with underground storage:

1. economical, in terms of both investment and maintenance costs;
2. structural stability;
3. storage is fireproof and protected from extensive damage caused by internal explosion;
4. large volumes can be stored and expansion can be undertaken economically;
5. mined mineral produced can be a valuable byproduct;
6. efficient use of land; and
7. aesthetically appealing, causes the least amount of interference with the surface environment.

There is some potential for possible conflicting resource utilization regarding Nova Scotia's salt deposits and the development of underground storage caverns. The current and future potential uses of the

province's domal and bedded salt deposits include dry salt mining, solution mining, oil and gas exploration/development, chemical reaction chambers, space utilization for underground structures, long-term hazardous waste storage, hydrocarbon storage and compressed air storage for peaking power.

The development of the American Gulf coast salt domes for SPR hydrocarbon storage occurred in a somewhat haphazard fashion governed largely by political, economic, and technological developments. Nova Scotia contains vast geological resources of salt which to date have been underutilized. We now have the opportunity to properly implement land use policies and resource planning to account for potentially conflicting resource utilization plans. The vast quantity of salt available ensures that there is more than sufficient reserves for conventionally or solution mined product for use as a consumer and industrial commodity. Abundant additional resources are available for use as storage cavern sites and other potential developments discussed above.

Innovative planning may allow for complimentary uses of the resource to optimize economic and technical benefits and minimize any environmental impacts. An example of this would be the decision to develop a sodium chloride-based chemical industry while simultaneously developing solution mined cavities for hydrocarbon storage.

The general parameters which need to be addressed in developing long range resource utilization plans for Nova Scotia's salt deposits include economic, environmental, logistical and technical factors.

5.7 Costs

5.7.1 Cost Elements

The major cost elements for construction of an underground facility in salt are:

- . exploration;
- . land acquisition;
- . well drilling and completion;
- . leaching facilities (water intake, water pipeline, main pumping station, field pipelines and manifolds, cavern pad, blanket system, brine separator, brine pipeline, brine pumps, and general facilities);

- . cavern development (labour, services (eg. surveys), power, and maintenance);
- . cavern dewatering (if applicable) - (labour, services, power, and maintenance);
- . cavern retrofitting (labour and services);
- . cavern filling (labour, services, power, and chemicals);
- . testing and acceptance; and
- . engineering.

5.7.2 Cost Estimates

The following estimates were included in the Strategic Petroleum Reserve Plan dated January 1977: "The total cost of an 80 million cubic metres (500 million barrels) strategic petroleum reserve is estimated to be between \$7.5 and \$8.0 billion US. Approximately 89 percent of the cost will be for purchasing and transporting crude oil (assuming an average cost of \$13 US per barrel); 9 percent is for acquisition and construction of storage facilities; about 2 percent is for filling, maintaining, and managing the reserve. The average cost of construction and land acquisition is estimated at between \$1.38 and \$1.65 US per barrel and will occur primarily in the earlier periods of the development."

It is estimated that current (1988) storage development costs will range from \$2 to \$3 US per barrel (\$17 to \$25 Cdn. per cubic metre). Assuming a crude oil cost of \$18 US per barrel, the current per barrel cost for a strategic petroleum reserve is (the same percentile cost allocation described above still applies):

BUDGET	COST		
	<u>% of Total</u>	<u>Cost (US \$/bbl)</u>	<u>(\$Cdn./m³)</u>
Acquisition & construction	9	2.0	17
Fill*, maintain and manage	2	0.5	4
Crude purchase and transport	89	20.0	168
	<u>100</u>	<u>22.5</u>	<u>189</u>

The per barrel cost is independent of the size of the reserve being considered. It is dependent on the average volume of each individual cavern; larger caverns are more economical (\$/bbl) to develop. If the owner of the storage facilities and the owner of the crude oil are not the same, the cost of crude oil is not to be included in the cost of the reserve.

Costs indicated herein represent guidelines only. Storage development costs are dependent on a number of factors, such as type of salt available; proposed development schedule; raw water acquisition system; brine disposal system; proximity of pipelines, terminals and power sources. Costs are also affected by the specific nature of the storage; i.e. storage to serve a long-term emergency supply, commercial surge operation requiring relatively high fill and drawdown rates, etc. Manpower requirements will also vary significantly on a site to site basis, with major differences in requirements for a strategic (dead) storage site and an active transshipment facility. These questions must be settled on a site (and project) specific basis.

5.8 Substance-Specific Design Considerations

5.8.1 General

This section applies the design criteria discussed in Sections 5.1 to 5.7 to the storage of the substances being considered in this study.

Many of the criteria for salt cavern storage are common to all types of storage. One of the factors which differs is the storage depth (which is dependent on specific pressure requirements). Figure 5-9 shows a schematic representation of the most desirable depth intervals for developing caverns for the storage of crude oil, liquefied petroleum gas, natural gas, compressed air, and hazardous waste. Cavern operation requirements also impact on depth selection and are addressed in the figure. This information is very approximate and mainly intended to help

* Includes cost of additional labour for operations and cost of energy to operate equipment during the fill period.

TYPES OF SALT CAVERN STORAGE

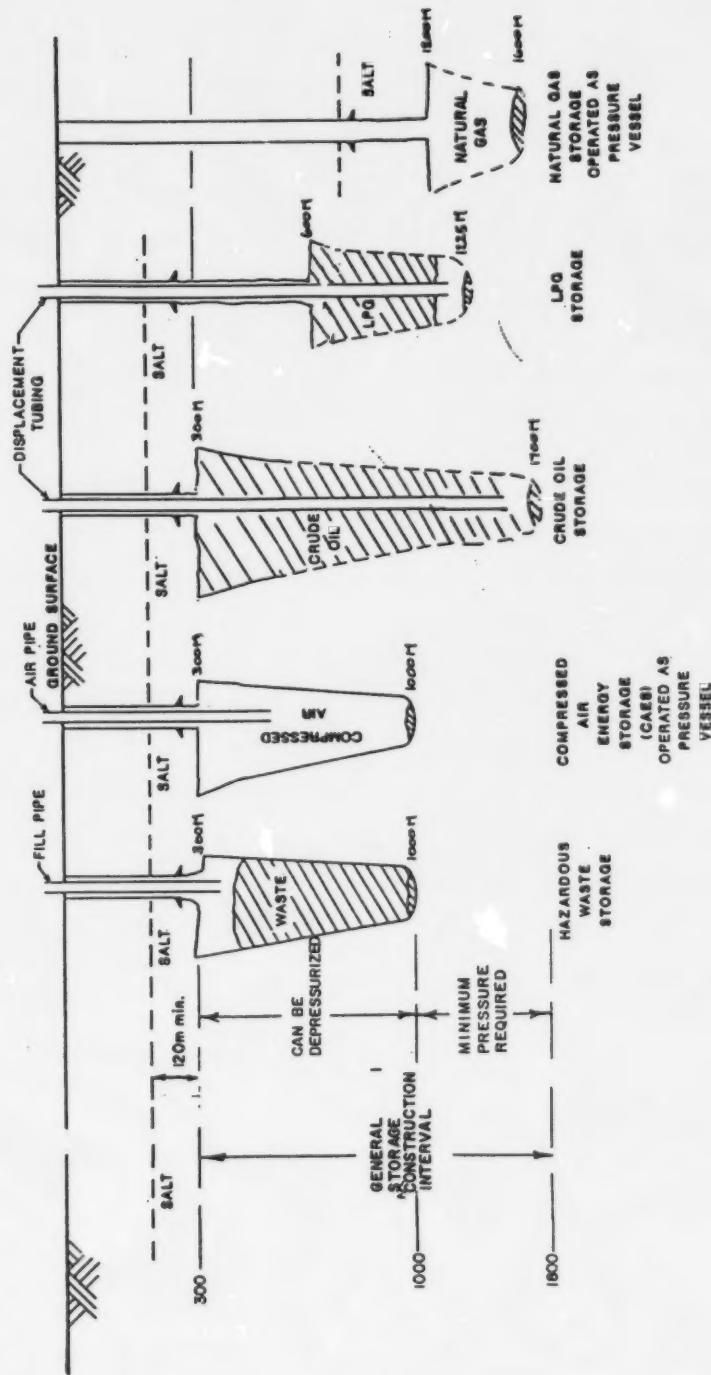


FIGURE 5-9

OPTIMAL DEPTHS FOR VARIOUS CAVERN STORAGE SUBSTANCES

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visualize the different requirements for the various storage types. The storage depth may be altered to suit variable geological conditions at specific sites and project specific requirements.

Three major requirements apply to the selection of storage depth:

- The minimum thickness of overlying strata required to provide adequate sealing is normally 300 metres (1000 feet) from the surface to the last cemented casing shoe depth. This is the upper limit of the storage potential interval.
- A minimum salt roof (S) of 120 metres (400 feet) (which may be part of the 300 metres of overlying strata).
- The maximum storage depth is limited to 1800 metres (6000 feet), due to the increased creep closure rate experienced at greater depths.

The useful depth interval to be considered for any storage development project is therefore from 300 to 1800 metres (1000 to 6000 feet).

The 1000 metres (3300 feet) depth is the typical limit for construction of caverns requiring a full depressurization. Caverns located deeper require a minimum pressure to be maintained at all times.

Table 5-1 summarizes the most desirable depth intervals for various storage substances.

TABLE 5-1
Most Desirable Depth Intervals

Stored Substance	Economic Depth (m)	Interval (ft)
Crude Oil	300 - 1700	1000 - 5600
LPG	600 - 1225	2000 - 4000
Natural Gas	1200 - 1600	3900 - 5300
Compressed Air	300 - 1000	1000 - 3300
Hazardous Waste	300 - 1000	1000 - 3300

The storage volume requirement is essentially dependent on the type of substance being stored: liquid (incompressible) or gas (compressible). In the case of liquid storage, the volume of liquid stored is equal to the geometrical volume of the cavity. In the case of gas storage, the storage volume required is a function of the pressures and temperatures involved. As previously mentioned, the maximum and minimum pressures are the leading parameters determining the storage capability of gas storage caverns and the specific storage costs.

Figure 5-10 shows the relationship between the cavern geometrical volume and the cavern dimensions (height and diameter), for cylindrical caverns.

Figure 5-11 shows the relationship between the cavern operating pressure range and last cemented casing shoe depth. Larger differential pressures and therefore larger working gas volumes for the same cavern geometrical volume are allowed for depths from 1200 to 1600 metres (3900 to 5300 feet).

Figure 5-12 illustrates the relationship between the cavern geometrical volume and the working gas volume for different values of operating pressure. Temperature effects were not accounted for, although they are not negligible.

5.8.2 Crude Oil

The storage of crude oil and other low-vapour pressure liquids is the most flexible of all the storage substances being considered in regard to allowable depths and sizes of the storage caverns. The relatively low operating pressure (brine head pressure) allows the caverns to be located at shallow depths without fear of exceeding the effective vertical stress. Greater depths are limited primarily by economic considerations. Allowable cavern size is also very flexible. Existing caverns range in capacity from about 50,000 cubic metres (a few hundred thousand barrels) to one which contains 6 million cubic metres (38 million barrels) for the SPR. The average size of the crude oil storage caverns proposed for the Strait of Canso area salt deposits during the late 1970's was approximately 0.3 to 0.8 million cubic metres (2 to 5 million barrels).

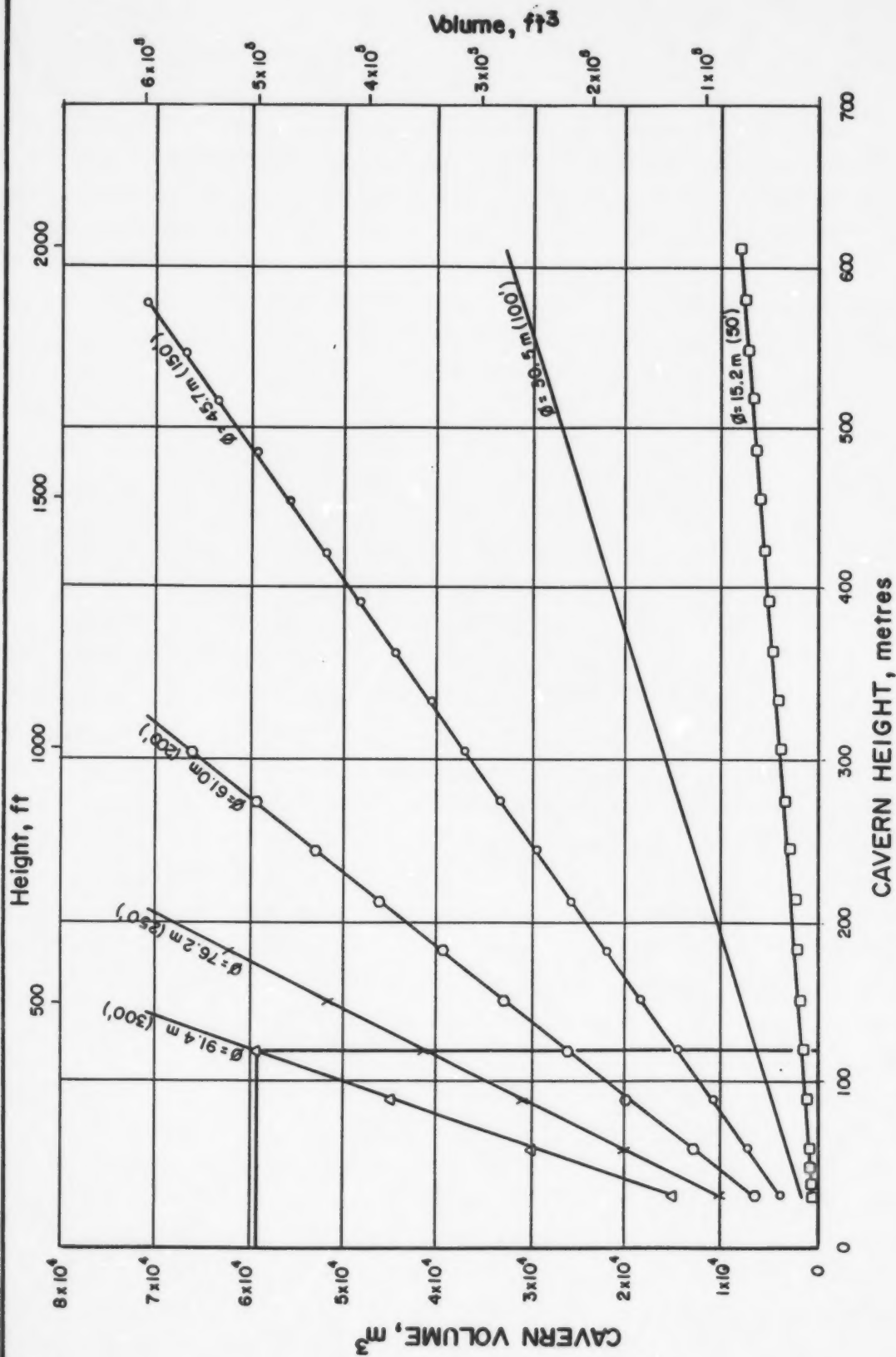


FIGURE 5-10
RELATIONSHIP BETWEEN CAVERN VOLUME AND
CAVERN DIMENSIONS FOR CYLINDRICAL CAVERNS

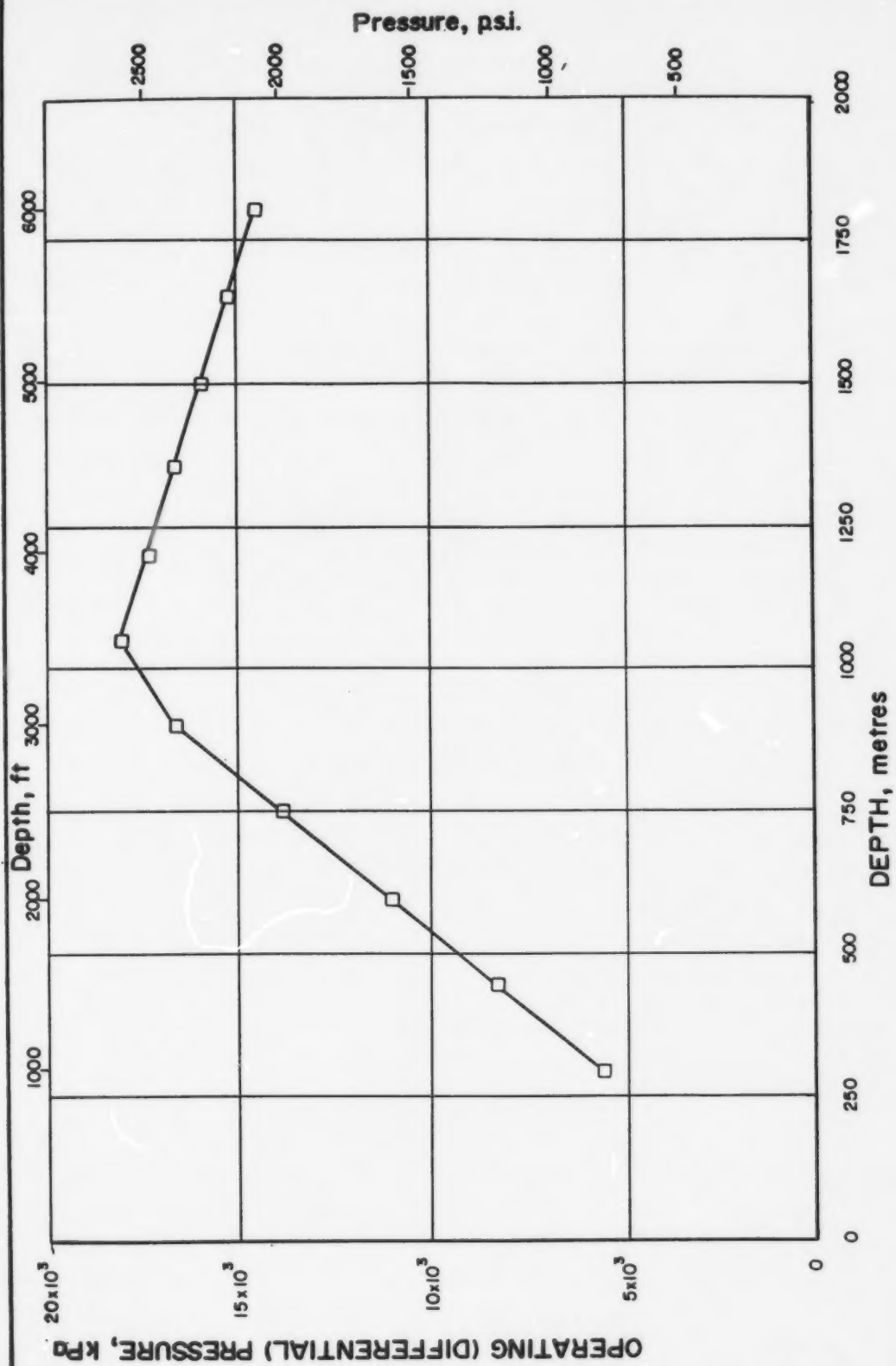


FIGURE 5-11

RELATIONSHIP BETWEEN CAVERN OPERATING PRESSURE
AND THE LAST CEMENTED CASING SHOE DEPTH



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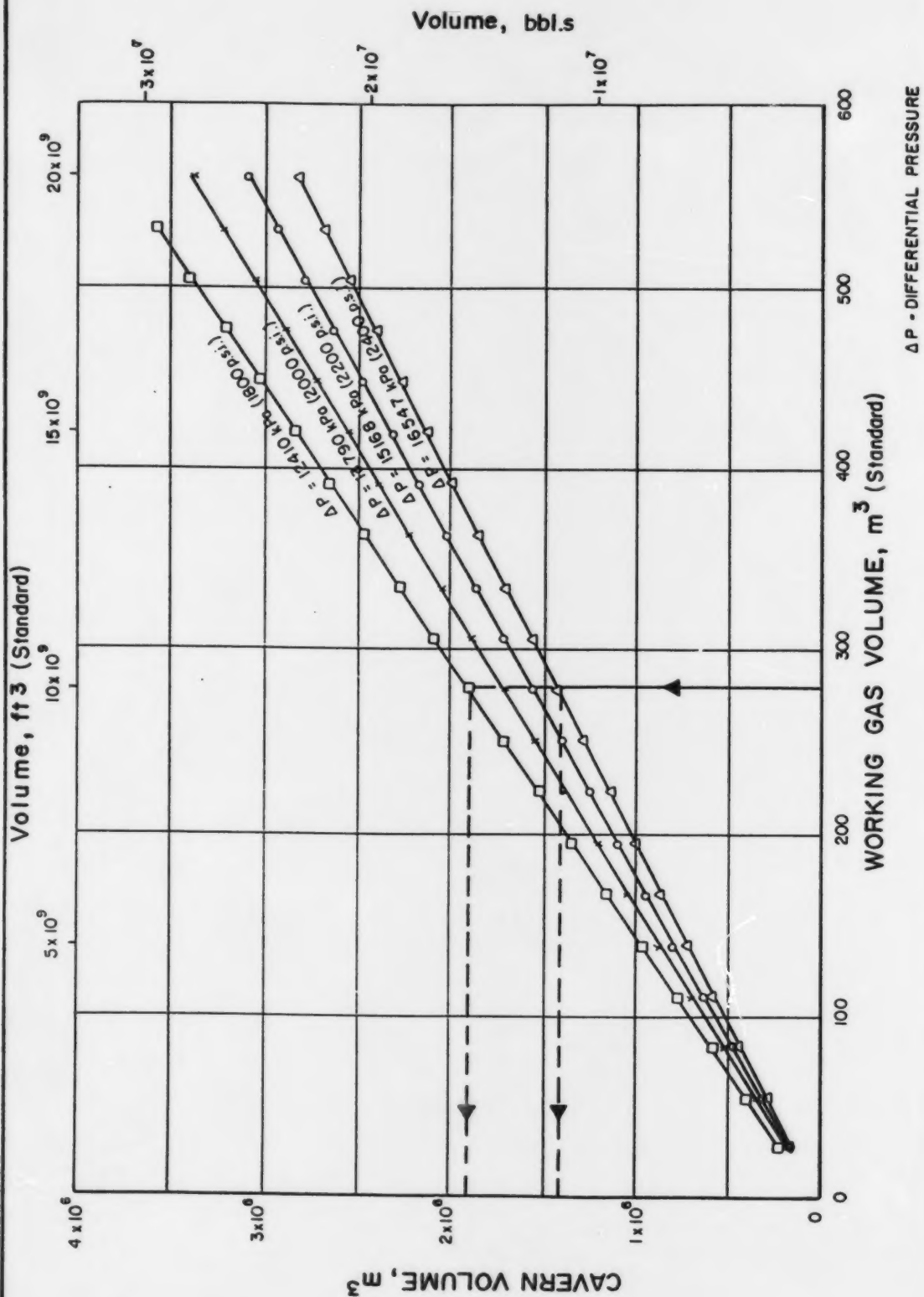


FIGURE 5-12

RELATIONSHIP BETWEEN CAVERN VOLUME & WORKING GAS VOLUME

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Pillar to diameter (P/D) requirements for cavern stability are moderate for crude oil storage because of the relatively high specific gravity of crude oil and the fill/displacement technique used. Current designs usually place P/D values between 1 and 2. Given that a particular salt deposit with a significant halite section is determined to be relatively free of impurities (interbedded insolubles), the technical feasibility for oil storage will depend on the quantity of salt below that elevation required to provide adequate sealing, and the areal extent of the salt deposit.

5.8.3 Liquefied Petroleum Gases

The term liquefied petroleum gases or LPG includes commercial butane and propane, and mixtures of both of these products. Other substances which come under this category and are sometimes stored in solution cavities are ethylene, propylene, natural gas-liquid mixtures, olefin feed stock, isobutane, and butylene. However, butane and propane and mixtures of these two are by far the most common. The vapour pressure of LPG only slightly exceeds that of crude oil and associated products, but not enough to make a significant difference in the large-scale requirements of the salt deposit.

A slightly thicker roof thickness is generally desirable to compensate for the moderately increased pressures. Also, the percentage and type of interbedded insoluble layers, especially in the upper section of the halite, are important to identify. This is true for all categories of storage substances, but especially for LPG storage.

Experience has shown that insoluble layers, particularly fine-grained clastics such as shale (or isolated boudins of anhydrite), tend to slough off and kink or break the pipe within the cavern during the solution mining process. Operating costs increase if the tubing has to be replaced or repaired. If during the filling cycle, the brine tubing string breaks in the (upper) LPG sector, above the brine level in the cavern, the product will flow out the brine string tubing to the pond or other brine-storage area (Dreyer, 1982). Careful attention must also be paid to zones of swelling clays or potash mineralization (particularly carnallite).

5.8.4 Natural Gas

This substance requires the highest pressure range of all those being considered, and consequently, requires the greatest depth of salt. Thus, the primary selection criteria are a suitable thickness of sufficiently pure salt at a (considerable) minimum depth, usually at least 1000 metres. Because of the cyclic extreme pressure differential involved in filling and emptying the cavity, the loss of volume in the storage cavern due to creep is of greater concern in this application.

Salt temperature and rock mechanical properties are critical parameters in the final cavern design for natural gas storage. Gas caverns are normally operated "dry". Initially, the brine is removed from the cavern by displacement with gas or by pumping. The pressurized gas is injected into the cavern and can be recovered by self-expansion. The maximum allowable pressure depends on the fracture gradient and depth of the formation.

The differential pressure (difference between the cavity pressure and the overburden pressure) is an important parameter in assessing the long-term creep behaviour of the cavity. This differential pressure can range between zero and the maximum allowable differential pressure during the operation of the natural gas storage facility. There is a critical differential pressure for each salt cavity operation which depends on cavity depth, number of cavities per site, material properties (i.e. geological conditions), and the mechanics of the storage operation. The maximum allowable differential pressure is set at a safe limit below the estimated critical value. After leaching individual cavities, it is advisable to test for leak-tightness prior to filling with gas. It is also advisable to pre-determine the allowable range of cavity pressure prior to cavity development.

The number of cavities developed at a particular site is significant factor in assessing long-term creep closure. It has been observed that when more than one cavity is created in a salt formation, each of the cavities undergo a greater rate of creep than if only one had been developed (Chao, 1973). This effect is due to the superposition of stress changes in the formation upon the creation of each cavity.

5.8.5 Compressed Air Energy

Cavern depth requirements for compressed air energy storage (CAES) vary depending on the capacity and type of energy storage system that is used. For a Nova Scotia CAES development, it will primarily depend on the inlet pressure range allowed by the type of gas turbine chosen for retiming the cyclic energy generated by the potential Fundy Tidal Power Project or other peak shaving electrical generating station. Many of the design criteria applicable to natural gas caverns are also applicable to compressed air, since both are pressurized. A CAES cavern must initially be evacuated of liquid and after that, is continuously subject to pressure cycling similar to a natural gas storage cavity.

Rock mechanics properties become important at the cavern design stage for compressed air storage caverns as well. Pillar to diameter ratios are significant, requiring more space between each cavern. However, since flow rates are high relative to cavern volume only a moderate increase in cost is involved in developing a greater number of smaller caverns. Other material properties required to assess cavern stability include specific weight, heat capacity and conductivity, moisture content, compressibility (bulk modulus), and permeability. Based on these and other parameters, the fatigue limit of the salt rock can be determined for a given deposit based on laboratory testing of salt core samples. An estimate of the engineering life of the proposed cavern can be made based on these test results.

Efficient use of a CAES plant requires that either fuel oil or natural gas be mixed with the compressed air which is withdrawn from the cavern to power the combustion turbine. Consequently, it makes sense to consider the use of salt caverns for fuel oil or natural gas storage in conjunction with compressed air storage. The turbo-machinery already in place for the CAES plant could be used to compress the natural gas (Gustin, 1983).

5.9 Geologic and Rock Mechanics Evaluation Criteria

This section addresses the geological factors which must be evaluated to assess the feasibility of utilizing individual salt deposits for storage of liquid and gaseous hydrocarbons and compressed air. Many of

the geological criteria required for salt cavern design are common to all types of storage, but with varying degrees of significance. The principal concerns in the initial site selection process are listed below:

1. Salt section of sufficient thickness and relatively free of impurities or fractures so that it can be rendered impermeable by the solution process, and provide an economical cavern height and structurally sound cavern shape.
2. Sufficient thickness and type of roof or caprock (impermeable layers minimize the required thickness of salt to bound the cavern; highly permeable layers such as karstic limestone or breccia are undesirable).
3. Sufficient depth to permit confinement and adequate section between the cavern roof and surface to allow effective well completion (optional depths vary with the different storage substances and subsequently affect costs).

It is likely that salt zones in excess of 100 metres thickness with insoluble contents of less than 10 percent will be relatively low in some of the structurally more complex salt deposits of the province. In these cases, a number of vertically "stacked" caverns can be engineered to maximize volume by available cavern height. This has been done successfully in other areas, but requires a high degree of definition of the structure and stratigraphy of the salt deposit.

The geologic data on the known salt deposits and occurrences in Nova Scotia is outlined briefly in the preceding section (4.0). The amount of data available for the various deposits is very uneven, some deposits being known only from one borehole which only partially penetrated the salt section; others having been extensively explored and/or developed by drilling, gravity and seismic surveys, conventional underground mining, and solution mining methods. This makes it difficult to properly assess and compare the geological merits of various sites on a detailed scale. In any case, this is not necessarily the most desirable approach at this scale of feasibility assessment. The best approach is to broadly categorize those deposits which are geologically suitable based on megascopic (large scale) characteristics (depth to salt beds, available thickness, relative degree of purity, etc.). Then one can assess the economic and technical factors (proximity to production or transfer point, proximity to market,

environmental acceptability, cost estimates, etc.). These considerations will be the over-riding criteria in ranking sites which are deemed suitable based on megascopic geological characteristics. Having thus established the most favourable sites, the next phase is collection and assessment of site-specific geological data.

The latter is the methodology used in this study. Specific sites which appear to be favourable based on the initial, broad scanning of geological features and technical/economic criteria are discussed on a detailed geological basis in Part C of this report. Recommendations are made regarding the type of supplementary data required for those sites which are not well defined. The types of detailed data required for cavern design within a particular salt deposit are also outlined.

For regularly bedded salt deposits whose characteristics are generally known and for domal salt deposits, it can often be assumed with a high degree of confidence that the salt is of sufficient purity and thickness for development of storage caverns. This was confirmed by examination of drill cores from the relatively flat-lying (structural Type A) bedded Shubenacadie-Stewiacke deposit and other Type A or B (flat-lying to gently folded) deposits. This greatly simplifies the initial screening process for these types of deposits. In highly deformed deposits with complex folding, such as most of those in Europe and parts of the Gulf Coast, coring is often required to determine initial feasibility. This would be true of the Structural Type C and D deposits of Nova Scotia as well. Evidence of this was found at Port Richmond when Dow Chemicals encountered drilling problems with unpredicted insoluble layers resulting from the complex stratigraphy and structural configuration of the deposit.

In many of the highly deformed German deposits, it has been necessary to locate caverns precisely within high quality folds. This will limit the precision of feasibility conclusions which can be drawn for the more complex (C and D types) deposits of Nova Scotia; but fortunately most of these deposits have some borehole information upon which to base general assessments of suitability.

After a salt deposit has been deemed suitable for development of storage caverns based on the broad scanning of available geological and technical data, a more detailed assessment of specific parameters is

required to determine the storage potential (possible storage substances and storage volume) at each site and to provide input to cavern design. Some of the parameters required at this more detailed phase are listed in Table 5-2. The significance of knowledge of these parameters and implications for cavern design and development are discussed below.

As previously discussed, many of the salt deposits of Nova Scotia appear favourably constituted for underground storage based on megascopic features. These salt deposits, together with their enclosing envelope of salt-saturated evaporite strata (anhydrite, marlstone, mudstone, etc.), would provide potential storage repositories having negligible primary porosity or permeability through interconnected pore spaces. The bulk of the salt sections are sealed below the depth of groundwater influence. Special geologic conditions were required for the creation of such impermeable deposits. Moisture content, temperature, pressure, and geologic time are four important variables influencing the storage characteristics of a given deposit.

During the formation of a salt-deposit, inter-crystalline brines must be gradually reduced through evaporation to a moisture content of a fraction of one percent. During this process, most of the inter-crystalline salt pore spaces, as well as the pore spaces of the enclosing strata (marlstone, mudstone, anhydrite, etc.), become filled with salt or other evaporite minerals. Temperature is an extremely important factor in determining the mobility of salt crystals in a salt mass. Higher temperatures result from greater previous depth of burial or proximity to external heat sources (volcanic or igneous activities such as sills, dikes, etc.).

The gradual accumulation and subsequent compaction of sediments overlying the salt deposit produce confining pressures that contribute to the final closing of pore spaces within the salt beds and enclosing evaporite strata. Over geologic time, pressures of only a few kilopascals will cause pressure solution and recrystallization of adjoining salt crystals or salt granules - regardless of shape or size. Pressure solution upon the touching of the salt grains, particularly those mobilized by

temperature and moisture, will yield at least three optically distinct salt entities. The youngest entity, corresponding to the least stress condition, fills the remaining pore space between salt grains.

TABLE 5-2

**Geological Parameters Required for
Detailed Cavern Feasibility Study**

1. <u>Megascopic Geological Features</u>	4. <u>Hydrogeology</u>
Salt Depth Salt Thickness Utilization History	Dissolution Features (e.g. Karst Topography) Salt Springs at Surface Porosity Data Permeability Data Deleterious Fluids (Ground- water, Brine, Gas Pockets) Depth of Groundwater Influence Previous Drillholes, Wells into Salt Deposits
2. <u>Structural Geological Features</u>	5. <u>Geophysics</u>
Folding Faulting Brecciated Zones Nature of Caprock/Salt Interface Seismic Activity Surface Subsidence	Detailed Gravity Survey High Resolution Seismics Downhole Geophysical Data
3. <u>Stratigraphy</u>	6. <u>Physical and Rock Mechanics Parameters</u>
Thickness of Enclosing (over- lying) Strata Discontinuities within Enclosing Strata Insoluble Material Content of Salt Highly Soluble Mineral Content (e.g. Potash) Geometry Structure and Distribution of Soluble/Insoluble minerals	Petrography (crystal character of salt) Geochemistry Temperature Moisture Content Tensile Strength Compressive Strength Thermal Conductivity Thermal Diffusivity

These processes require long periods of time to convert an initially porous and permeable evaporite deposit to a non-porous, impermeable condition. This time frame is measured in millions of years (geologic time). The concept is important because relatively short-term events (earthquakes, etc.) can cause local and temporary disruptions of the normally non-porous and impermeable sheath.

Secondary porosity and permeability result from the development of joints, fractures, and faults; anomalies usually caused by relatively short-term seismic or tectonic stresses and strain. Occasionally, human activities (such as heavy construction, blasting, mining, drilling, or liquid injection) may cause, or at least contribute to, such features. The anomalies resulting in such secondary porosity and permeability can usually be identified during preliminary site geological and engineering studies, and thus can be avoided when developing storage.

It is very important to obtain all relevant historical data on the previous use of a particular salt deposit prior to designing a cavern. In the early period of American Gulf Coast brine production, many uncontrolled brining cavities were created when little knowledge about controlling the cavity shape was available. Brine pockets were often formed near the surface of the dome and no supporting "roof" of rock salt was maintained, often resulting in sinkholes from collapse of the overlying sediments.

The history of exploration of the various deposits, particularly the location and depth of all boreholes, is important to determine prior to final cavern design. Boreholes which may have been drilled a considerable number of years in the past may not have been adequately recorded or documented. If these boreholes were not properly sealed, and are discovered only after a storage cavern is created, it can cause significant problems. If old, abandoned, boreholes are located prior to cavern development, they may either be avoided as undeveloped zones, or they can be properly sealed and isolated from connection with the proposed storage cavity.

It is important to define the stratigraphy and structure at the sites selected (especially the more complex C and D structural types) prior to final cavern siting and design. A preferred direction of dissolution

has been observed in some solution mined cavities, as evidenced by elongate cross-sections rather than the ideal circular (horizontal) cross-section. This inhomogeneity is caused by a variety of factors; weak salt zones, gas or brine pockets, highly soluble potash minerals such as sylvite and carnallite, or other inclusions.

These trends are of primary concern regarding the structural integrity of salt caverns, but are often not predictable or noticed until solution mining is underway and sonar surveys are taken to determine cavern shape. Also of concern is the amount of interbedded insoluble layers (e.g. anhydrite), particularly near the upper part of the salt section which may fall off during the solution process and damage the casing string(s) suspended in the cavern. Frequent surveys, especially during the initial part of cavern development and sophisticated, controlled, brining techniques will help to minimize potential problems.

The nature of the caprock and overlying strata is important to establish. In some areas, active dissolution of salt layers is ongoing, as evidenced by the presence of salt springs near the deposit. Other highly permeable zones, such as cavernous or vuggy limestones, may be encountered during drilling. If a high rate of circulation or lost circulation exits in this zone above the salt deposit, the following are potential concerns:

- . corrosion of the casing and other pipes connecting the cavern to surface facilities;
- . construction problems may result from open spaces encountered during drilling and the hole may collapse;
- . a leak in the casing may undesirably affect cavern stability by allowing a rapid pressure drop; and
- . intersection of pressurized oil, gas or hydrogen sulphide pockets is a safety concern during the drilling process.

Few direct measurements of the porosity of salt have been made; however, a value in the order of one percent may be taken as representative of Gulf Coast salt domes with values ranging from 0.2 to 6.0 percent. Measurements of water content in salt are generally very low - less than one percent, and frequently less than 0.1 percent (Kelsall and Nelson, 1983).

Rock salt behaviour is strongly temperature dependent. Unfortunately, temperature data is very scarce or generally unreliable for Nova Scotia salt deposits; but this type of data really only becomes critical at the cavern design stage. Well log temperatures are unreliable unless fluids in the well have been allowed to equilibrate over a number of months. Temperatures recorded in mines are also not representative, unless measured away from the influence of rooms.

All material strength properties of salt samples determined in a laboratory for purposes of cavern design should be denoted as typical for salt at a certain temperature. Unfortunately, because of its nature, the physical parameters measured on a salt sample taken from a borehole will not be identical to the sample in situ, under the existing lithostatic pressure. In any case, all available rock strength data must be used to design caverns which will experience minimal creep over their expected life span.

Empty cavities with overburden pressures greater than 21 MPa and temperatures of 200 degrees Celsius will start to close. The amount of closure increases with depth because of increasing pressure and temperature since the viscoplastic property of salt is dependent on both temperature and pressure. At depths of up to 1520 metres (5000 ft.), the temperature will most likely not exceed 82 to 88 degrees Celsius under normal geothermal gradients, and under these conditions, stable cavities can be constructed (Corcoran et.al, 1973). It is assumed in this calculation that the cavity will not be pressurized or filled with liquid at all times. The degree to which this varies will depend on whether the cavern is to be used as a strategic hydrocarbon reserve (used only in emergency situation) or trans-shipment facility, or the specific cycling/retiming regime, if it is a CAES facility.

Physical properties of salt rock have been investigated by numerous workers. A large body of knowledge has evolved from the SPR program in the salt domes of the Gulf Coast region of the United States. Table 5-3 lists typical engineering properties for the Gulf region salt dome deposits which are used in cavern design calculations.

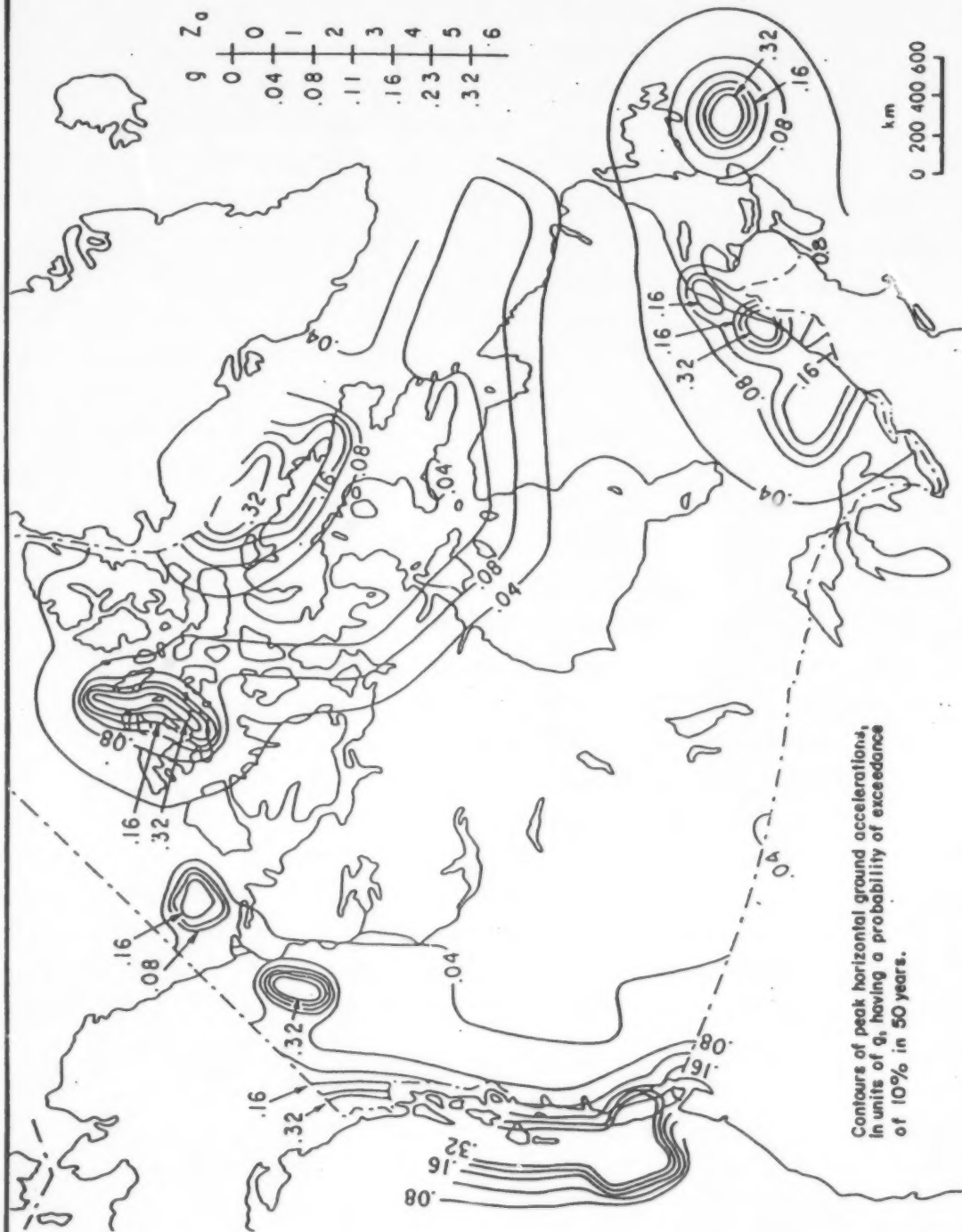
Another important consideration in site selection for storage caverns is the seismic stability and earthquake potential in the area being

considered. Eastern Canada has experienced less activity than some other areas of Canada, although recently central New Brunswick has experienced a relative increase in low magnitude earthquake activity. Figure 5-13 shows the peak horizontal ground accelerations, having a probability of exceedance of 10 percent in 50 years, from the National Building Code of Canada - 1985. This is based on a statistical analysis of seismic activity experienced in Canada and adjacent areas.

Figure 5-14 shows earthquakes and their relative magnitude which occurred in Eastern Canada in 1984. Based on both of these maps, one can see that Nova Scotia lies in a relatively quiet seismic zone. Generally, little damage may be expected from seismic events in this zone.

The eastern half of Cape Breton Island and the area near the Nova Scotia/New Brunswick border in Cumberland County are at a very slightly higher risk than the rest of the province, and the ground accelerations experienced from earthquakes in these areas may produce moderate damage (National Research Council of Canada, 1985). These areas are peripheral to earthquake epi-centres located in the Quebec City and Montreal-Ottawa areas, and in an offshore location to the east of Cape Breton (Figure 5-14). The salt deposits in the Sydney area would fall within a slightly higher risk zone (Figure 5-13).

Most potential cavern sites in Nova Scotia would experience limited ground shaking from distant regional earthquakes. As a result of the large volumes of storage substance, any shock wave generated by an earthquake would likely pass through the cavern and fluid as an elastic wave and not create any stress to the cavern (Home Oil et.al., 1979). Ground accelerations would probably be below those which would require special earthquake design features to be incorporated into the cavern development. However, National Building Code standards for earthquake-resistant design provisions are applicable to liquefied natural gas facilities, and these would have to be adhered to.



SOURCE: NATIONAL RESEARCH COUNCIL OF CANADA, 1985.

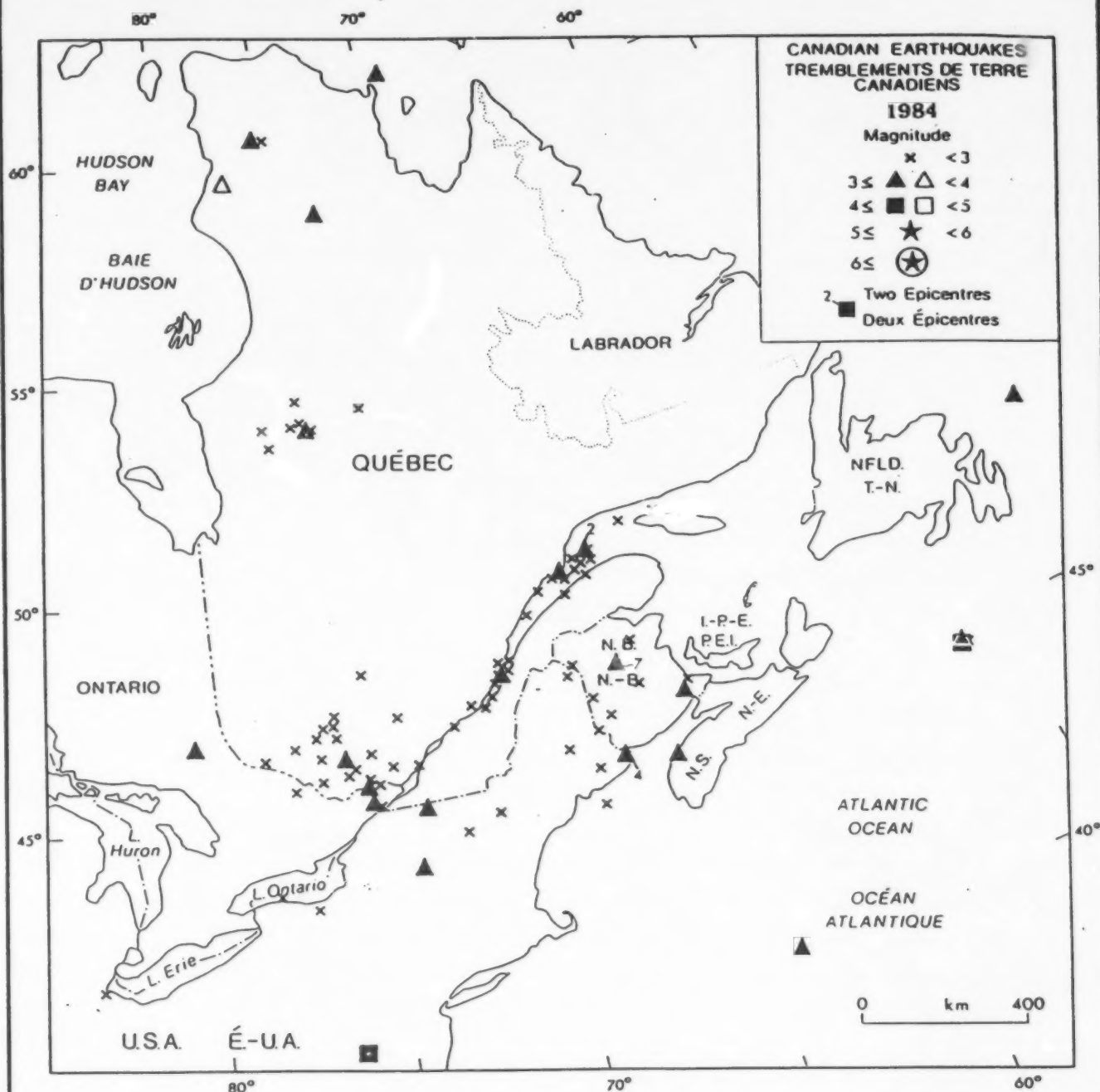


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FIGURE 5-13
PEAK HORIZONTAL GROUND ACCELERATIONS
CANADA

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Source: Drysdale and Horner, 1987: GSC paper 87-19



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**FIGURE 5-14
EARTHQUAKES OF EASTERN CANADA
AND ADJACENT AREAS 1984**

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TABLE 5-3

Representative Values of Engineering Properties of Gulf Region Dome Salts

Property (Units)	Range of Measured Values	Typical Value	Remarks
Bulk Density (g/cm ³)	2.10 - 2.23	2.16	Depends on porosity and degree of impurities.
Porosity (%)	0.2 - 6.0	<1.0	Not often measured directly.
Water Content (%)	0.001 - 1.7	<0.1	Sensitive to measurement technique, few comparable measurements on different salts.
Permeability (md)	0.0001 - 400	—	Significantly affected by sample disturbance, sensitive to confining stress.
- Laboratory	0.0001 - 400	—	
- Field	0.0001 - 0.011	0.001	
Tensile Strength (MPa)	0.2 - 3.5	1.0	Indirect measurement (Brazilian test), at room temperature.
Unconfined Compressive Strength (MPa)	8 - 29	23	At room temperature.
Young's Modulus (GPa)	21 - 42	30	Values from unload/reload cycles in quasistatic tests at room temperature.
Poisson's Ratio	0.15 - 0.5	0.35	Values from unload/reload cycles in quasistatic tests at room temperature.
Creep Properties	—	—	Site-specific - dependent on wide variety of factors.
Thermal Conductivity (W/mK)	2.0 - 6.5	5	Decreases with increasing temperature; typical value corresponds to room temperature.
Thermal Diffusivity (m ² /s)	1.3-3.7 x 10 ⁻⁶	3 x 10 ⁻⁶	Decreases with increasing temperature, typical value corresponds to room temperature.
Coefficient of Linear Thermal Expansion (K ⁻¹)	4.7-5.7 x 10 ⁻⁵	5 x 10 ⁻⁵	Increases slightly with increasing temperature, very few measurements available.

(Source: Kelsall and Nelson, 1983)

PART C

SITE SPECIFIC GEOLOGICAL EVALUATION

PART C: SITE-SPECIFIC GEOLOGICAL EVALUATION

6.0 INTRODUCTION

This part of the report (Part C: Chapters 6 to 10) details the geological evaluation of the individual salt (halite) deposits under consideration and the evaluation process used to arrive at the selection of the best sites for development of storage caverns. Initially, all of the salt deposits or occurrences identified within the four designated geographic areas were considered as potential sites. All readily available geological, geophysical, engineering, environmental, and logistical data were collected and assessed for each of these sites. Individual "data forms" were completed for each of the sites, listing the relative amount and type of data available which would be most relevant to a storage cavern feasibility assessment. These data forms are found in Appendix B.

The format of the list of sites follows that of Boehner's (1986) report on the Salt and Potash Resources of Nova Scotia, whereby deposits and occurrences are grouped into geographic areas. This report and the individual data files on each site which were used to compile the report (located at the offices of the Nova Scotia Department of Mines and Energy - NSDME) formed the primary data source for this phase of the assessment.

These NSDME data files are fairly comprehensive and are divided into the following subfiles:

Subfile 1:	Historical Background
Subfile 2:	Geography and Physiography
Subfile 3:	Geological Data
Subfile 4:	Geophysical Data
Subfile 5:	Geochemical Data
Subfile 6:	Economic Considerations
Subfile 7:	Source Documents
Subfile 8:	Assessment of File Quality

Table 6-1 lists each of the sites within the four geographic areas under consideration and summarizes the most relevant geologic data upon which to base an initial broad-scoped feasibility assessment. Each site is designated as a "deposit" or "occurrence" by Boehner (1986). Those sites designated "deposits" generally have an economically significant thickness of salt defined by one or more boreholes. Those sites designated

"occurrences" generally have only thin uneconomical salt beds. The designation is a judgement based on the available data (generally gravity surveys and the borehole data), as well as comparisons of poorly defined sites with better-known salt deposits. Some "occurrences", however, are only known from one borehole which may have only partially penetrated the top of the salt section and they have the potential to be upgraded to "deposit" status with further exploration.

The amount of data available for the sites is highly variable. Some are defined only by a single borehole; and this may have only partially penetrated or fully proven the salt section. Others are known only from thin salt beds with a large body interpreted to be at depth from gravity surveys but unproven by drilling. Other sites, such as the Shubenacadie-Stewiacke deposit have been extensively explored and defined by drilling.

The approximate depth to the salt beds given in Table 6-1 is based, in some cases, only on one or two boreholes. Similarly the approximate thickness of the main salt section(s), in some instances is unknown and can only be estimated based on gravity interpretation models and comparison with similar better known deposits. These approximate depths to top of salt and salt thicknesses are the basis for the preliminary feasibility of developing storage caverns for the various substances discussed in this report.

The structural type of the deposit, based on Boehner's (1986) classification is also listed in Table 6-1. The classification system is based on the four letter types - A, B, C, and D, as discussed in Section 4.0 and illustrated on Figure 4-4.

The areal extent of the main salt section for each site is also given, most often based on Bouguer gravity anomalies and supplemented with drill hole data in many cases. Whether or not salt springs have been reported in the immediate vicinity of the deposit or the general region is also noted, as well as dissolution features such as karst topography. Salt springs generally indicate that active dissolution of halite is taking place somewhere in the subsurface strata. This may be taking place in the shallow subsurface above the main salt section where thin salt veins or saline carbonate rocks may be undergoing leaching. Alternatively, a

TABLE 6-1
PRELIMINARY ASSESSMENT OF GEOLOGICAL DATA

GEOGRAPHIC AREA AND SITE NAME	DEPOSIT OR OCCURRENCE	APPROXIMATE DEPTH TO TOP OF SALT (METRES)	APPROXIMATE THICKNESS OF MAIN STRUCTURAL SALT SECTION (METRES)	APPROXIMATE AREAL EXTENT OF DEPOSIT & DEGREE OF DEFINITION	SALT SPRINGS/DISOLUTION FEATURES NEAR DEPOSIT	STATUS/PRIOR UTILIZATION OF DEPOSIT
NORTH-COLCHESTER AREA						
BEAVER BROOK	DEPOSIT	400 (UPPER SALT) 630 (MAIN SALT)	103 CONFIRMED (N. ENDED IN SALT) 300-400 PROBABLE	B 3.0 X 1.0 KM POORLY DEFINED	NO	NOT CURRENTLY UTILIZED. GOOD POTENTIAL FOR FURTHER EXPLORATION/DEVELOPMENT.
CLARESVILLE	OCCURRENCE	271 (UPPER SALT) 358 (LOWER SALT 1) 637 (LOWER SALT 2)	300 ± MINIMUM CONFIRMED	B-C 3.0 X 10.0 KM POORLY DEFINED	SALT SPRINGS IN REGION EAST TOPOGRAPHY	NOT CURRENTLY UTILIZED. GOOD POTENTIAL FOR FURTHER EXPLORATION/DEVELOPMENT.
FALMOUTH	OCCURRENCE	165	3 (THIN BEDS ONLY)	F UNKNOWN POORLY DEFINED	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED. NOT CONSIDERED ECONOMIC.
KENNETCOTE	OCCURRENCE	404 (UPPER SALT) 409 (LOWER SALT)	5 (UPPER SALT) CONFIRMED 14 (LOWER SALT) CONFIRMED	B-C STRUCTURAL CONFIGURATION, EXTENT UNKNOWN. APPROXIMATELY DEFINED BY NARROW TROUGH-LIKE GRAVITY ANOMALY	SALT SPRINGS, EAST TOPOGRAPHY NEAR DEPOSIT	NOT CURRENTLY UTILIZED. NOT CONSIDERED ECONOMIC AS KNOWN. POTENTIAL FOR OTHER SALT OCCURRENCES NEARBY
SUBERACADIE-STEWARTS DEPOSIT	DEPOSIT	300 (DEEPEST PART OF BASIN) 180 (PERIPHERAL AREAS)	300 (CENTRAL PART OF BASIN)	A 40.0 X 8.0 KM (ELONGATED BASIN) WELL DEFINED	NAE	NOT CURRENTLY UTILIZED. EXCELLENT POTENTIAL FOR FURTHER EXPLORATION/ DEVELOPMENT.
STANLEY	OCCURRENCE	350	14 CONFIRMED (BOREHOLE ENDED IN SALT)	B-C 4.0 X 6.0 X 6.0 TRIANGULAR GRAVITY ANOMALY APPROXIMATELY DEFINED	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED. POTENTIAL FOR FURTHER EXPLORATION.
SUNNEVILLE	OCCURRENCE	308 (UPPER ZONE) 414 (LOWER ZONE)	THIN INTERBEDS OF SALT ONLY (IN TWO ZONES: 380-388 AND 414-425)	VEIN 0.3 X 1.3 KM POORLY DEFINED	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED. NOT CONSIDERED ECONOMIC.
UPPER WALTON RIVER	OCCURRENCE	277 TO 344 (VARIABLE) LIMITED BOREHOLE DATA IS IMPRECISE. SALT THICKENESS VERY COMPLEX	10 MINIMUM CONFIRMED. SIGNIFICANT SALT/SHALE SECTION PROBABLE AT DEPTH	C ILL DEFINED TROUGH-SHAPED GRAVITY ANOMALY. POORLY TO APPROXIMATELY DEFINED	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED. POTENTIAL FOR FURTHER EXPLORATION.
WALTON	OCCURRENCE	355 TO 412 (VARIABLE) LIMITED BOREHOLE DATA WIDELY SPACED	43 AND 43 MINIMUMS CONFIRMED FULL EXTENT UNKNOWN	B-C POORLY DEFINED GRAVITY ANOMALY WITH WIDELY SPACED SURVEY LINES COMPLEX GEOLOGY	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED. NOT CONSIDERED ECONOMIC.
CUMBERLAND AREA						
BEESWITH	OCCURRENCE	310 (ONE BOREHOLE INTERSECTED BEHIND SALT ONLY). SALT DOME STRUCTURE PROBABLE AT 430-440	3 (THIN BEDS, VEINS ONLY)	C-B APPROXIMATELY DEFINED BY GRAVITY SURVEY (CIRCULAR-OVAL SHAPED ANOMALY INDICATES 207M RADIUS AT 2316M DEPTH)	NO	NOT CURRENTLY UTILIZED. POTENTIAL FOR FURTHER EXPLORATION.
MALAGASH	DEPOSIT	30-450 (DIPPING SEAM; ANTICLINE STRUCTURE)	123 (APPROXIMATE TRUE THICKNESS)	D WELL DEFINED (PREVIOUSLY MINED). GRAVITY ANOMALY COVERS AREA 1.5 X 9.0 KM	SALT SPRINGS NEAR DEPOSIT	NOT CURRENTLY UTILIZED. POTENTIAL FOR FURTHER EXPLORATION. AREA WEST OF FORMER UNDERGROUND MINE.
WAPPAN	DEPOSIT	225 TO 400 (VARIABLE) 340 AVERAGE	1400 (INDICATED FROM DEEP OIL WELLS IN REGION)	D MODERATELY WELL DEFINED DIAPYRIC STRUCTURE COVERING BROAD AREA WITH 1400 METER SALT THICKNESS	EAST TOPOGRAPHY, SALINE PONDS, NEAR DEPOSIT	CURRENTLY EXPLOITED BY BONTAR LTD. (SIFTO SALT SILVERING) BY BRINE.
OXFORD	DEPOSIT	466 (ONE BOREHOLE INTERSECTED MAIN SALT) 110 (TOP OF RIZED SALT). MUDSTONE AMPHIBOLITE SECTION)	17M MINIMUM CONFIRMED (BOREHOLE ENDED IN SALT)	D MODERATELY WELL DEFINED ELLIPSESHAL GRAVITY ANOMALY 6.0 X 3.0 KM	SALT SPRINGS NEAR DEPOSIT	NOT CURRENTLY UTILIZED. POTENTIAL FOR FURTHER EXPLORATION. (SOME POTASH INDICATED)

TABLE 6-1 (CONTINUED)

GEOGRAPHIC AREA AND SITE NAME	DEPOSIT OR OCCURRENCE	APPROXIMATE DEPTH TO TOP OF SALT (METRES)	APPROXIMATE THICKNESS OF MAIN STRUCTURAL SALT SECTION (S) (METRES)	TYPE	APPROXIMATE AREAL EXTENT OF DEPOSIT & DEGREE OF DEFINITION	SALT SPRINGS/DISSOLUTION STATUS/PRIOR UTILIZATION FEATURES NEAR DEPOSIT	CURRENTLY MINED UNDERGROUND (ROOM AND PILLAR) BY CANADIAN SALT CO. LTD.
PUGWASH	DEPOSIT	200-300 (VARIABLE)	1500M (INDICATED BY SEISMICS)	D	WELL DEFINED (EXISTING UNDERGROUND MINE). DEPOSIT FOLLOWS WINDSOR OUTCROP AREA (0.8 X 3.0 KM)	SALT SPRINGS NEAR DEPOSIT	NOT CURRENTLY UTILIZED.
ROSLIN	OCCURRENCE	MAIN SALT NOT REPRESENTED BY WINDSOR SALT BRECCIA WITH SALT VEINS FROM 114 TO 304M.	UNKNOWN (PRESENCE INDICATED BY GRAVITY SURVEY)	B	GRAVITY ANOMALY INDICATES A SMALL COMPLEX SALT DIAPIR AT DEPTH	SALT SPRINGS NEAR DEPOSIT	NOT CURRENTLY UTILIZED. SALT DEPOSIT POTENTIAL FOR FURTHER EXPLORATION.
CARSO-BRAS D'OR AREA CLEVELAND	DEPOSIT	732 (ONE BOREHOLE)	332 MINIMUM CONFIRMED (BOREHOLE ENDED IN SALT)	B-C	POORLY DEFINED	SALT SPRING IN REGION	NOT CURRENTLY UTILIZED. GOOD POTENTIAL FOR FURTHER EXPLORATION. (SOME POTASH INDICATED)
ESTHER	DEPOSIT	400 (ONE BOREHOLE)	441 MINIMUM CONFIRMED (BOREHOLE ENDED IN SALT)	B-C	POORLY DEFINED	SALT SPRING IN REGION	NOT CURRENTLY UTILIZED. GOOD POTENTIAL FOR FURTHER EXPLORATION.
KINGVILLE	DEPOSIT	400-600 (VARIABLE) 430 AVERAGE	700 CONFIRMED	C-D	MODERATELY WELL DEFINED 1.0 X 3.0 KM GRAVITY ANOMALY	SALT SPRING IN REGION	NOT CURRENTLY UTILIZED. DONTAR INDICATED PROVEN RESERVES OF 28.6 MILLION TONNES, CARRIED OUT SUCCESSFUL BRINING TEST AND CONSIDERED SITE FOR CRUDE OIL STORAGE.
MCINTYRE LAKE	DEPOSIT	96-237 (VARIABLE- COMPLEX STRUCTURE AND STRATIGRAPHY) 330 AVERAGE	614 MINIMUM CONFIRMED BOREHOLE ENDED IN SALT	C	APPROXIMATELY TO POORLY DEFINED 1.0 X 10.0 KM GRAVITY ANOMALY	NIGHTLY PERMEABLE LIMESTONE OVER SALT FOUND IN DRILLING	NOT CURRENTLY UTILIZED HOME OIL COMBUSTION CONSIDERED DEPOSIT FOR SPR OIL STORAGE SITE OF CANADIAN TRANS-SHIPMENT FACILITY.
MALACAWATCH	DEPOSIT	230	329 MINIMUM CONFIRMED	CT	MODERATELY WELL DEFINED 1.0 X 3.0 KM GRAVITY ANOMALY	SALT SPRING IN REGION	NOT CURRENTLY UTILIZED. CHEVRON CARRIED OUT DETAILED POTASH EXPLORATION DRILL PROGRAM 1981. POTENTIAL FOR FURTHER EXPLORATION.
ORANGEDALE	DEPOSIT	170-600 (VARIABLE) 300 AVERAGE	180 MINIMUM CONFIRMED (WITH ADDITIONAL INTERSECTED THINNER SECTIONS)	CT	MODERATELY WELL TO APPROXIMATELY DEFINED. BROAD GRAVITY ANOMALY 15.0 X 11.0 KM	SALT SPRING NEAR DEPOSIT	NOT CURRENTLY UTILIZED. MOLARSA EXPLORATION CO. LTD. CARRIED OUT POTASH EXPLORATION DRILL PROGRAM. POTENTIAL FOR FURTHER EXPLORATION.
PORT RICHMOND	DEPOSIT	250 - 350 500 TYPICAL	1000 CONFIRMED (BUT INTERSECTED INSOLUBLE BEDS PRESENT)	C-DI	APPROXIMATELY DEFINED, VERY COMPLEX STRUCTURALLY. HIGH AMPLITUDE GRAVITY ANOMALY, 4.0 KM DIAMETER	NO	NOT CURRENTLY UTILIZED. SOL CHEMICAL PRODUCED TWO TEST CAVES IN 1975 FOR POSSIBLE OIL STORAGE BUT DEFERRED PLANS.
SEAVIEW	OCCURRENCE	500	160 MINIMUM CONFIRMED (AS VEINS AND IN SHALE/ SILTSTONE SHEET)	C	POORLY DEFINED, GRAVITY ANOMALY 4.0 X 6.0 KM	SALT SPRINGS IN REGION	NOT CURRENTLY UTILIZED NOT CONSIDERED ECONOMIC AS KNOWN BUT POTENTIAL FOR FURTHER EXPLORATION
ST. PATRICKS CHANNEL	DEPOSIT	400	778 CONFIRMED	C	POORLY DEFINED (ONE BOREHOLE)	EAST TOPOGRAPHY IN REGION	NOT CURRENTLY UTILIZED POTENTIAL FOR FURTHER EXPLORATION
ST. PETERS	DEPOSIT	550	130 (SALT VEINS IN SILTSTONE -MAIN SALT NOT INTERSECTED)	C	POORLY DEFINED (THREE BOREHOLES ON ELONGATE GRAVITY ANOMALY)	SALT SEEPAGE ALONG FAULT IN REGION	NOT CURRENTLY UTILIZED POTENTIAL FOR FURTHER EXPLORATION. MAIN SALT MASS INFERRED FROM GRAVITY TEST TO BE DRILLED

TABLE 6-1 (CONTINUED)

GEOGRAPHIC AREA AND SITE NAME	DEPOSIT OR OCCURRENCE	APPROXIMATE DEPTH TO TOP OF SALT (METERS)	APPROXIMATE THICKNESS OF MAIN STRUCTURAL SALT SECTIONS (METERS)	TYPE NO.	APPROXIMATE AREAL EXTENT OF DEPOSIT & NATURE OF DEFINITION***	SALT SPRINGS/DISSOLUTION STATUS/PAUSE UTILIZATION FEATURES NEAR DEPOSIT OR DEPOSIT
STREET AREA ----- BOULDERBIE	DEPOSIT	300	33)	A-2	POORLY DEFINED (ONE BOREHOLE)	DEEP TROUGH IN ST. ARRESE CHANNEL INFERRED GOOD POTENTIAL FOR FURTHER TO BE RESULT OF SOLUTION AND REGIONAL EXPLORATION COLLAPSE OF WINDSOR EVAPORITES
EAST RAY	OCCURRENCE	284	3) (INTERBEDDED SALT)	A	POORLY DEFINED (ONE BOREHOLE)	NO NOT CURRENTLY UTILIZED NOT CONSIDERED ECONOMIC AS KNOWN BUT POTENTIAL FOR FURTHER EXPLORATION

*DEPOSIT OR OCCURRENCE: THE DESIGNATION IS ARBITRARILY BASED ON DEFINED SALT THICKNESS
(DEPOSIT IS GENERALLY GREATER THAN 100 METERS - SEE TEXT) AND
SOME OCCURRENCES HAVE THE POTENTIAL TO BE UPGRADED TO DEPOSIT
STATUS WITH FURTHER EXPLORATION.

**STRUCTURAL TYPE: FOR EXPLANATION OF LETTER DESIGNATION SEE FIGURE 4-4.

***DEGREE OF DEPOSIT/OCCURRENCE DEFINITION BASED ROUGHLY ON FOLLOWING GUIDELINES:

- WELL DEFINED - GRAVITY SURVEY + 12 OR MORE DRILL HOLES
- MODERATELY WELL DEFINED - GRAVITY SURVEY + 5 TO 12 DRILL HOLES
- APPROXIMATELY DEFINED - GRAVITY SURVEY AND/OR <5 DRILL HOLES
- POORLY DEFINED - 1 OR 2 BOREHOLES +/- GRAVITY SURVEY
- UNKNOWN - 1 BOREHOLE OR GRAVITY SURVEY (INCONCLUSIVE)

fracture zone or other discontinuity may be present at the salt/enclosing strata interface, providing a channel-way for groundwater to dissolve the upper salt section.

Residual breccias are common above the salt sections of some Nova Scotia salt deposits, indicating that a portion of the halite has been dissolved previously where saline Windsor Group strata have occurred near the surface. The absence of salt springs in the vicinity of a salt occurrence suggests that dissolution has been reduced or halted possibly by the sealing action of overlying soil strata, often associated with carbonate and gypsum resistites in some areas (Boehner, 1986). The widespread occurrence of salt springs throughout Windsor Group outcrop areas of the province indicates that many salt areas are not completely sealed. However, this potential problem can be evaluated on a site-specific basis and caverns designed to allow for these undesirable features if the dissolution area is localized and well defined.

The last column of Table 6-1 lists the current status of each site (i.e. whether it is currently being mined or otherwise utilized) and an assessment of the relative potential for further exploration.

Based on an initial scanning of the data used to compile this table, six sites were eliminated from further consideration, generally because of insufficient salt thickness and/or other undesirable characteristics.

These sites and the reasons for eliminating them are listed in Table 6-2.

Of the remaining sites, a list was compiled of those sites for which insufficient data was available to make anything but a cursory assessment of the geological feasibility of storage cavern development. These are generally sites where only one or two boreholes have partially penetrated the upper part of the salt or a large salt body is inferred at depth (from gravity data) but unproven by drilling. These sites are broadly assessed in terms of other economic and technical factors which may indicate that the site is suitable for storage cavern development.

TABLE 6-2

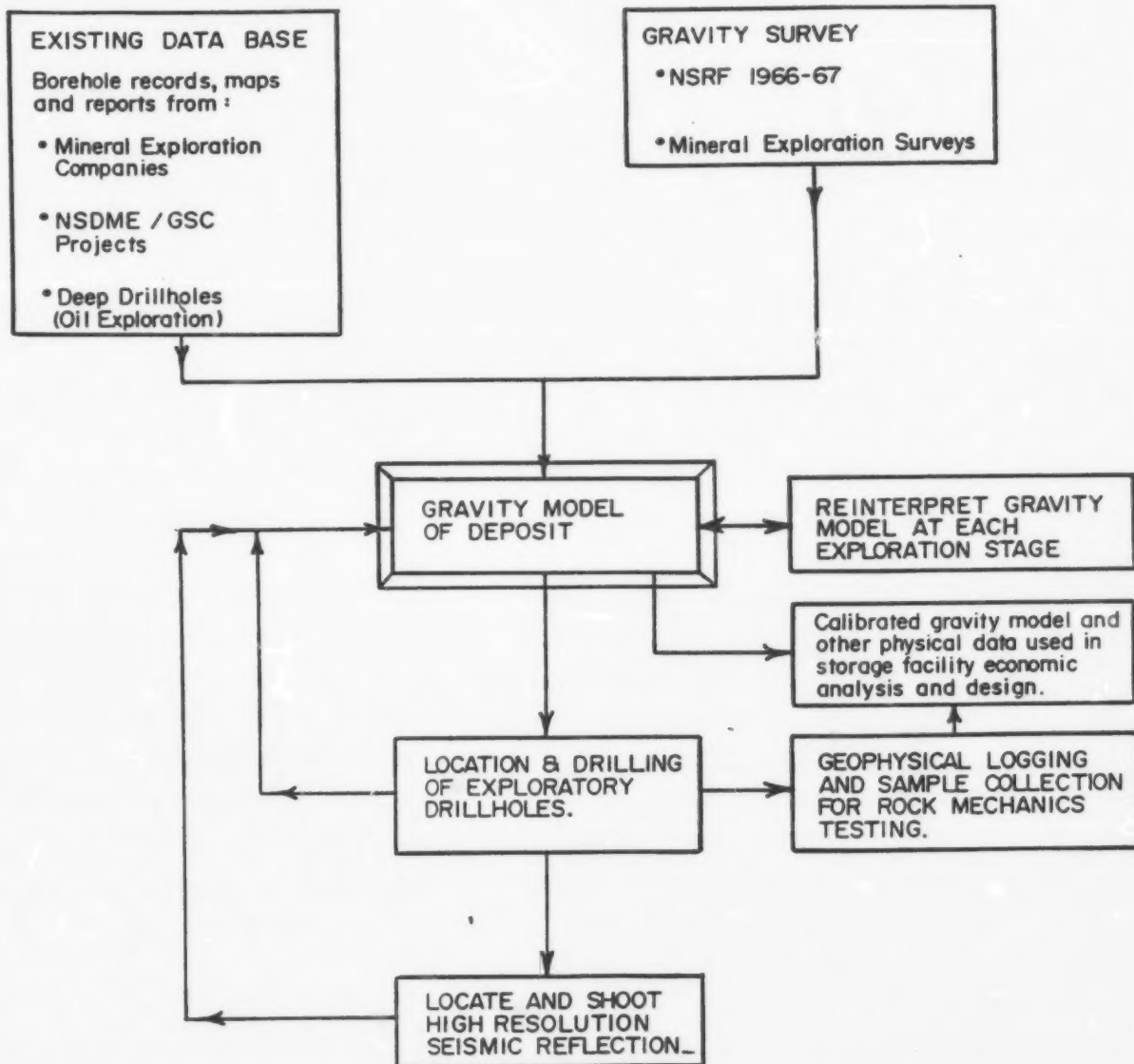
Sites with Insufficient Salt Thickness

<u>Site</u>	<u>Reason for Elimination</u>
Hants-Colchester Area	
Falmouth Occurrence	Minor salt beds only; mainly anhydrite.
Kennetcook Occurrence	Uneconomic salt quantities.
Summerville Occurrence	Thinly bedded salt and veins in uneconomic quantities.
Upper Walton River	Not considered economic; very complex structurally, site is inaccessible.
Walton	Not considered economic; site is inaccessible.
Cumberland Area	
Roslin	Not considered economic; inferred small, complex diapir.

Table 6-3 lists those sites for which insufficient data is available for an initial geological feasibility assessment. It also makes brief recommendations on what further data would be required to properly assess site suitability, and provides notes on the potentially suitable storage substances for each site.

Figure 6-1 shows the typical sequence of exploration stages to be followed in assessing the various salt areas to determine the size and configuration of individual deposits. Gravity surveys were carried out over most Windsor Group outcrop areas in the late 1960's by the Nova Scotia Research Foundation (NSRF). These gravity surveys and interpreted negative Bouguer anomalies generally provided drilling targets for subsequent salt, potash, and sulphur exploration programs.

The gravity modelling procedure makes use of the gravity data as well as all previous drill hole information and assumed sediment density values based on available information. The resultant interpretation is



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**FIGURE 6-1
SALT DEPOSIT EXPLORATION
SEQUENCE**

then used to locate boreholes and high resolution seismic lines over specific salt structure targets.

The gravity modelling of the deposit and stratigraphic correlation between boreholes must be constantly updated and refined as new data becomes available, particularly in the stratigraphically and structurally more complex (Type C and D) deposits. Geophysical logging of the boreholes aids in the interpretation of stratigraphy and identified insoluble layers. Rock core samples should be collected and preserved for material testing in those areas deemed most suitable for cavern development. Rock mechanics data, as well as temperature and moisture data, can then be compiled for input to the cavern design phase.

The sites which were not eliminated from detailed geologic evaluation because of insufficient thickness (Table 6-2) or insufficient data (Table 6-3) are described in the following four chapters (7.0 through 10.0). They are grouped into the four geographic areas under consideration. These sites represent the geologically most suitable deposits for storage cavern development, based on the data collected for this investigation.

The geology of each of the sites is described and the implications for solution mining and cavern development are discussed. Recommendations regarding additional data needed to fully evaluate the potential for the site are also made. In subsequent sections (Parts D and E) the other factors (environmental and economic, respectively) which must be taken into consideration for each site with the geological implications are evaluated and recommendations regarding the best overall sites for development are detailed in Part F.

7.0 HANTS-COLCHESTER AREA

7.1 General

Two salt deposits and several occurrences have been identified within the Hants-Colchester area. One of the deposits, the Shubenacadie-Stewiacke deposit, is well-defined (twenty drill holes into the salt section), whereas the other (Beaver Brook) is defined only by one borehole. However, it has good potential for further exploration. Many of the salt

TABLE 6-3

SITES WITH INSUFFICIENT DATA

SITE	GEOLOGY	POTENTIAL	FURTHER DATA REQUIREMENTS
<u>HANTS-COULCHESTER AREA</u>			
Stanley	Large Gravity Anomaly but lack of borehole data.	Possible Site For: 1. Crude Oil 2. CAES	Extensive Drilling Required.
<u>CINCINNATI AREA</u>			
Beckwith Occurrence	Salt veins only intersected in drilling to date. Large salt mass inferred from gravity to be at 450 to 600 metre depth.	Possible Site For: 1. Crude Oil 2. Compressed Air	Deeper Drilling to define depth, thickness, quality of salt.
Oxford Deposit	Orange halite veins in fractured shales, anhydrite, mudstone. Parent salt mass interpreted as anticlinal diapir, intersected at depth of 686 metres.	Possible Site For: 1. Compressed Air 2. Liquefied Petroleum Gases	Deeper drilling to define thickness, quality of salt. High resolution seismic survey and gravity modelling to define fault contacts, structural and areal extent of deposit.
<u>CANSO-ERAS D'OR AREA</u>			
Seaview Occurrence	Salt veins with shale-siltstone breccia only intersected to date.	Possible Site For: 1. Liquefied Petroleum Gases 2. Natural Gas	More regional drilling to define stratigraphy, presence of any significant salt thickness.
St. Peter's Deposit	Salt of variable purity with siltstone at average depth of 450 metres. Large part of main salt mass inferred to underlie St. Peter's Bay.	Possible Site for: 1. Crude Oil 2. Liquefied Petroleum Gases	Exploration to date is not encouraging. More regional drilling and deeper drilling on gravity anomalies required to define structure, stratigraphy, and salt sections.
<u>SYDNEY AREA</u>			
East Bay Occurrence	Interbedded salt anhydrite, sandstone, and limestone at depth of 284 metres. Main salt section may occur at greater depth.	Possible Site For: 1. Crude Oil 2. Liquefied Petroleum Gases	Deeper drilling on Dutch Brook Syncline required to establish presence of significant salt thickness.

occurrences in the area consist of thinly bedded, uneconomic halite sections (Table 6-2) and consequently are not discussed in this chapter.

7.2 Beaver Brook Deposit

7.2.1 Geology and Storage Cavern Implications

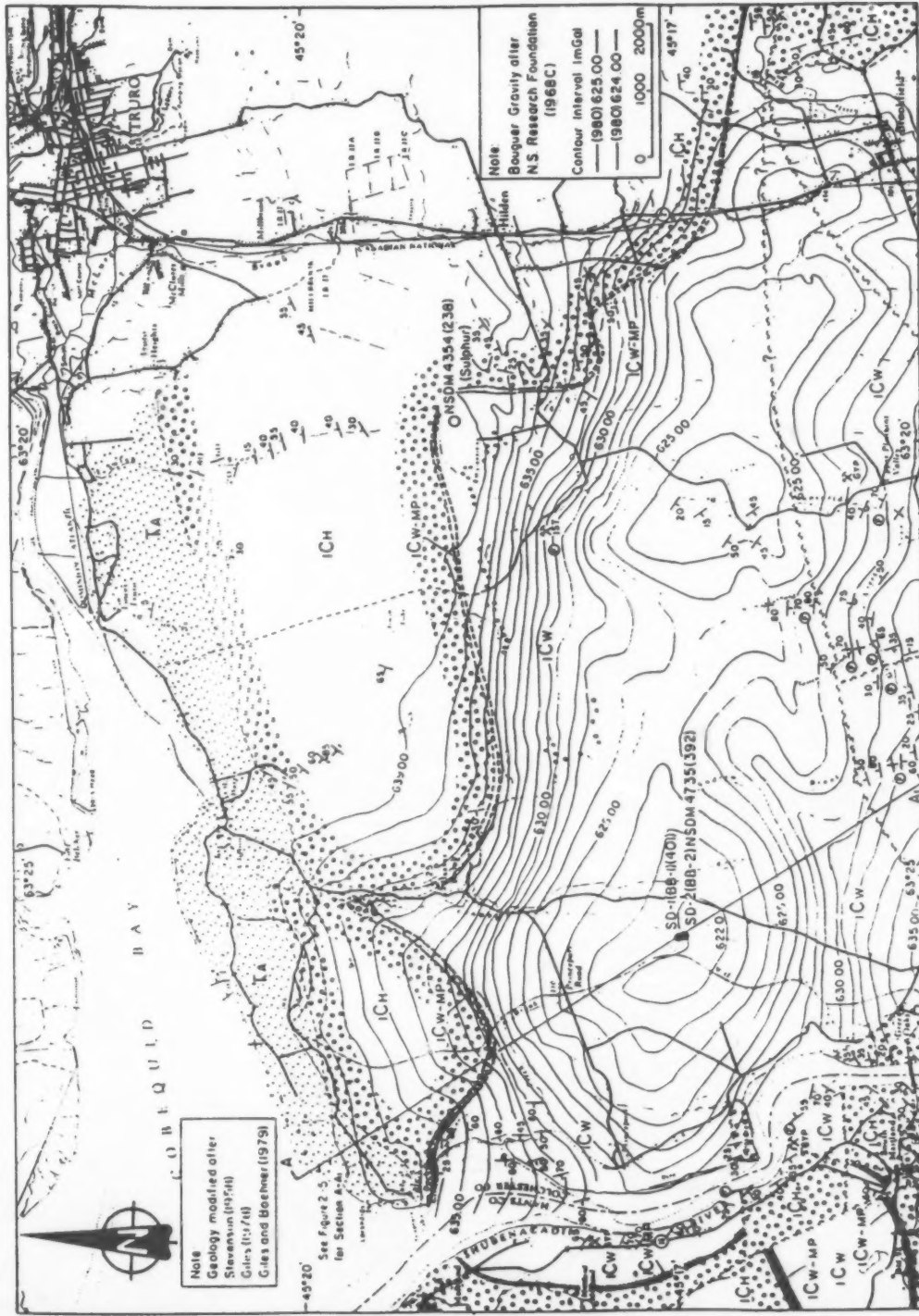
The Beaver Brook deposit is located within the "Shubenacadie Basin." It was originally assessed for its potash potential by Wright (1931) and a gypsum exploration program later revealed sulphur veinlets at shallow depths. Gravity surveys of the area defined a negative anomaly with the minimum located about half-way between Green Oaks and Beaver Brook. Two boreholes were drilled on the minimum (SD-1 by New Senator-Rouyn and Peel-Elder and SD-2 by NSDME - see Figure 7-1).

Salt was encountered at a depth of 392.0 to 411.5 metres (Upper Salt). The main salt section was intersected at 630 metres and the borehole ended in salt at 733.3 metres. The overlying strata consist of thick sections of clastics (sandstone and siltstone) with interbedded limestone and dolostone (Figure 7-2). The main salt itself is apparently relatively pure (average 89.63 percent soluble NaCl - Boehner, 1986) and free of interbedded insolubles. This would minimize potential problems with drill stem damage during the brining process.

The absence of salt springs in the area suggests that the salt body is well sealed from circulating groundwater, although this would have to be confirmed since there are apparently no low permeable (i.e. shale or clay) layers over the salt. No record of dissolution features was found for the overlying strata, although karst topography features are known in one area 3 to 5 kilometres east of the site near the contact with the Horton Group (Figure 7-1).

The map structure is interpreted as an east-west trending salt-cored anticline following the gravity anomaly (Boehner, 1986). The deposit is classified as a Type B - moderately deformed with open folds and moderate dips. Based on the gravity data, a thickness of 300 to 400 metres of salt is probable.

The depth and thickness of the salt section would make it potentially suitable for compressed air energy storage (it is located proximal to proposed tidal power plant sites on Minas Basin) and possibly



SOURCE BOEHNER, 1986



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FIGURE 7-10

GEOLOGY AND BOUGUER GRAVITY ANOMALY MAP FOR
BEAVER BROOK DEPOSIT

1187 607

MAR. 1988

LEGEND

TRIASSIC

KA ANNAPOLIS FORMATION: shale and sandstone

CARBONIFEROUS

UPPER CARBONIFEROUS

UCSV SCOTCH VILLAGE FORMATION: sandstone and shale

LOWER CARBONIFEROUS

WINDSOR GROUP

ICW Undivided siltstone, shale, anhydrite, gypsum, halite, and limestone

ICW-MP MACUMBER AND PEMBROKE FORMATIONS: limestone and limestone pebble conglomerate

HORTON GROUP

IC_H Undivided sandstone, shale and conglomerate

ORDOVICIAN

MEGUMA GROUP

OM Undivided slate and metasandstone

SYMBOLS

Heavily drift-covered area	
Rock outcrop, area of outcrop	
Limestone or dolomite outcrop (Faribault-Fletcher maps)	
Gypsum outcrop	
Geological boundary (defined, approximate, assumed)	
Bedding, tops known (inclined, vertical, overturned, horizontal)	
Bedding, tops unknown (inclined)	
Schistosity (inclined, vertical, dip unknown)	
Gneissosity (inclined, vertical)	
Plunge of minor fold	
Drag fold (arrow indicates plunge)	
Fault (defined, approximate, assumed)	
Fault (solid circle indicates downthrow side)	
Joint (inclined, vertical)	
Anticline (defined, approximate, arrow indicates direction of plunge)	
Syncline (defined, approximate, arrow indicates direction of plunge)	
Fossil locality	
Spore sample	
Glacial striae (ice flow direction known)	
Gravel deposit	
Quarry	
Diamond-drill hole	
Borehole	
Sinkhole	
Salt spring	
Observed karst topography	
Drillhole intersecting salt; number (depth to salt, metres)	
Drillhole without salt; number (Total depth, metres)	
Drillhole location precise to 150 m	

MINERALS

Anhydrite	ah	Limestone	lst
Gypsum	gyp	Pyrite	py
Lead	Pb	Zinc	Zn
Celestite	Sr		

SOURCE BOEHRNER, 1986



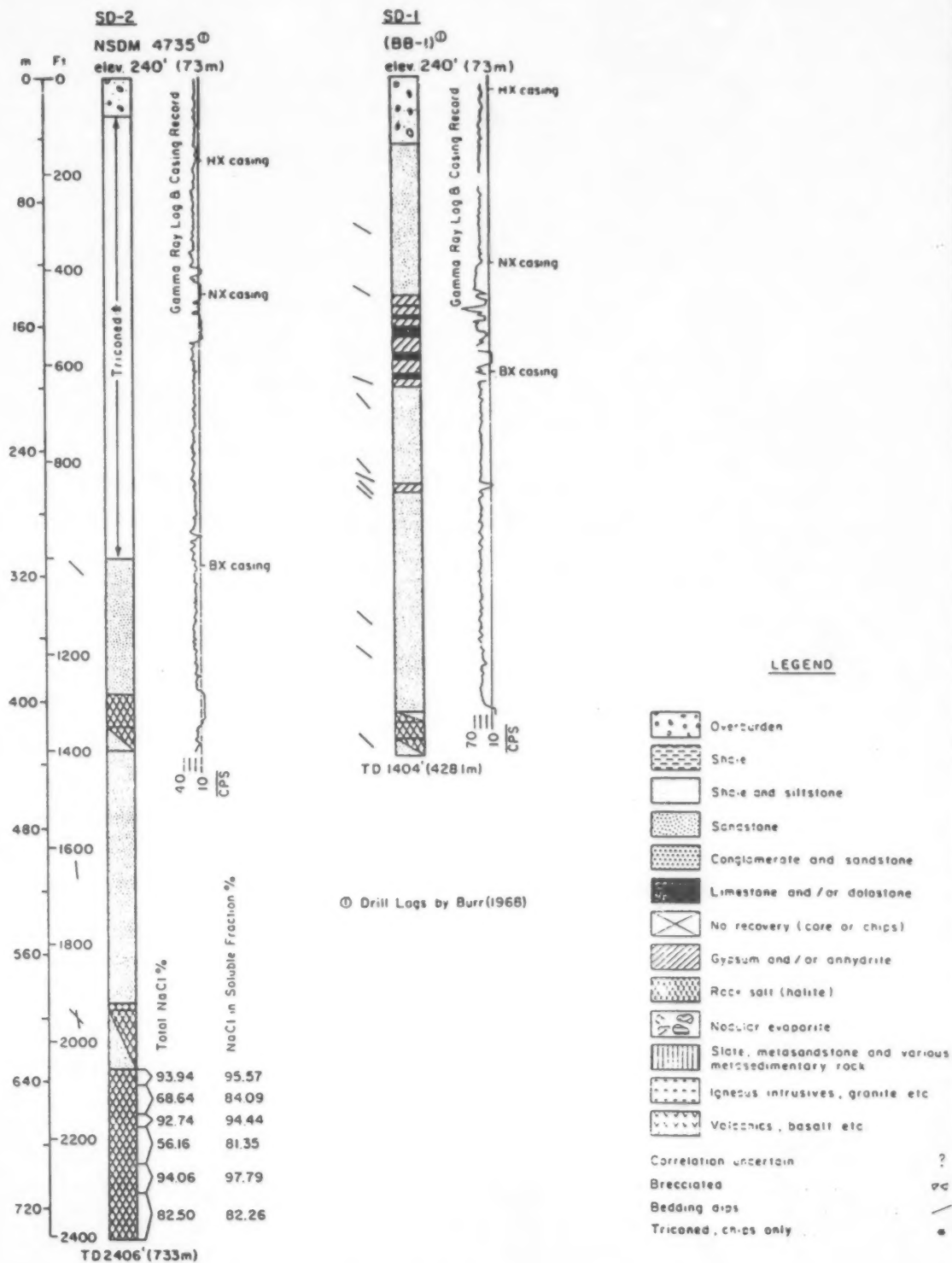
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FIGURE 7-1b

LEGEND

H87 607

MARCH 1988



SOURCE BOEHNER, 1986



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FIGURE 7-2
DRILLHOLE LOGS FOR
BEAVER BROOK DEPOSIT

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liquefied petroleum gases or crude oil, depending on economic factors. It most likely would not meet the depth and thickness requirements for natural gas and is probably unsuitably located with respect to markets.

7.2.2 Further Data Requirements

Deeper drilling is required on the gravity minimum to accurately define the main salt thickness and character (degree of interbedded insolubles, etc.). High resolution seismic reflection surveying would better define the structural configuration of the deposit (assumed to be an anticline). If the deposit is determined to be suitable for a storage cavern development site, based on acceptable salt thicknesses and extent, a regularly spaced drill hole survey with cores taken for material testing could be implemented. These data would be used for cavern design (optimum size and spacing calculations, etc.).

7.3 Clarksville Occurrence

7.3.1 Geology and Storage Cavern Implications

The Clarksville Occurrence consists of a steeply dipping interbedded halite and anhydrite sequence with a true thickness of less than 75 metres. The stratigraphy of the bedrock in the area is not well understood. Two boreholes were drilled in the area of the occurrence. Scurry-Rainbow drilled SR6-1 about 1.5 kilometres west of Clarksville (Figure 7-3) and intersected a thick clastic sequence. It is believed that this hole did not reach the underlying Windsor Group strata. Another hole, HC-1 (Figure 7-3), intersected a clastic sequence overlying a more steeply dipping interbedded anhydrite/shale section which overlies the anhydrite and salt section.

The entire section of HC-1 is interpreted as being younger than the uppermost Windsor Group limestone members (Boehner, 1986). The size and magnitude of the Bouguer anomaly suggests a large salt mass at depth, and if so, it is most likely the thickened Lower Windsor main salt (ibid.).

Cavern development could be suitable for storage of compressed air in conjunction with tidal power development, but the degree of structural discontinuities (fracture zones) in the overlying strata and their possible connection with the salt body would have to be determined



FIGURE 7-3

BOUGUER GRAVITY ANOMALY MAP OF
CLARKSVILLE AND OTHER OCCURRENCES

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SOURCE BOEHNER, 1986

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first. Precautions would be necessary when drilling through the overlying brecciated and veined halite beds and interbedded strata. Crude oil and/or LPG could conceivably be stored in caverns within the assumed lower salt section, but the economics would likely preclude locating them this deep in favour of deposits closer to the surface and more ideally located.

7.3.2 Further Data Requirements

Deeper drilling is required to establish the presence of the interpreted thick Lower Windsor salt section. Shallow seismic profiling and more regional drilling is needed to better define the stratigraphy and structural geology and correlate it with other Windsor Group sections. Once the presence of the deeper salt is confirmed, or otherwise, more detailed material testing, chemistry, temperature, and moisture data can be collected for the feasibility assessment and cavern design.

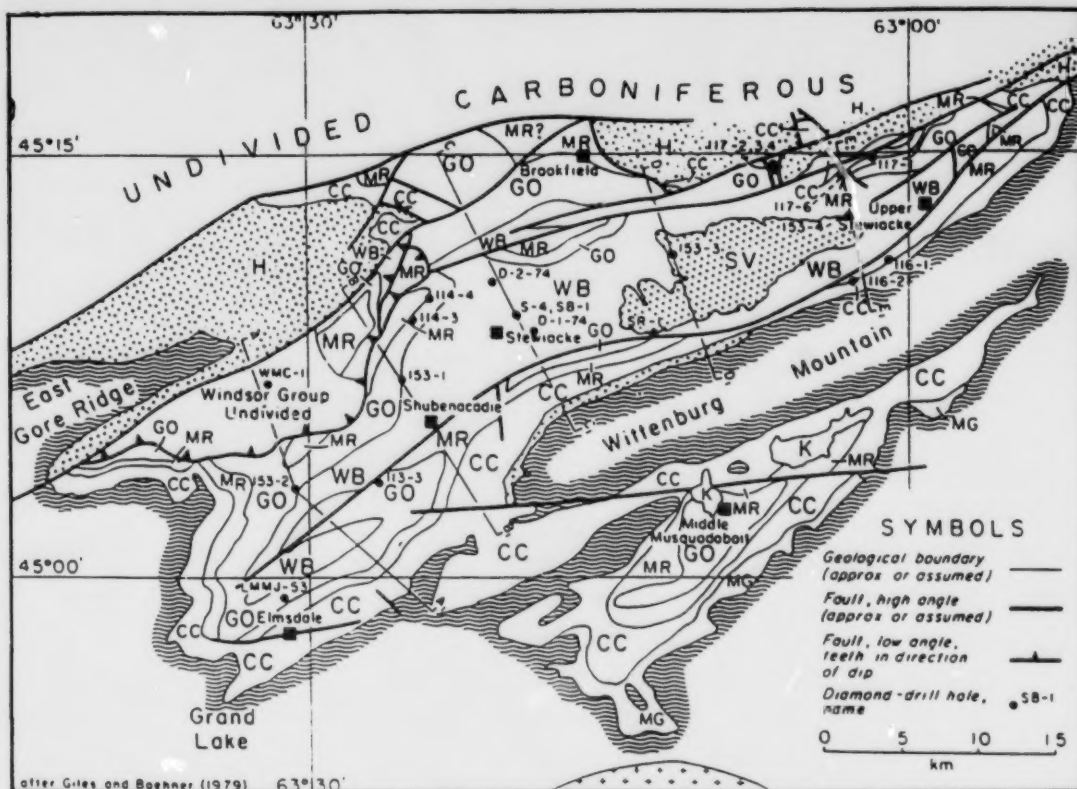
7.4 Shubenacadie-Stewiacke Deposit

7.4.1 Geology and Storage Cavern Implications

The Windsor Group stratigraphy and structure in the Shubenacadie-Stewiacke area has been recently studied in detail by Giles and Ryan (1976), Giles (1977), Boehner (1977a and b), Giles and Boehner (1979), Boehner (1980), and Giles and Boehner (1982a). Intensive exploration and drilling for base metal deposits following the discovery of the Gays River lead-zinc deposit, has also provided much subsurface data on the Windsor Group rocks in the area.

The Windsor Group in the area consists of limestone, dolostone, gypsum, anhydrite, halite, and siltstone/sandstone. This sequence is underlain by the Lower Carboniferous Horton Group clastic sequence, which in turn is underlain (angular unconformity) by the deformed Cambro-Ordovician Meguma Group metasediments. The geology of the Shubenacadie-Stewiacke area is shown in Figure 7-4.

The area is triangular in shape with the Wittenburg Mountain (topographic high) separating it from the Musquodoboit Valley which lies to the southeast. The southeastern border is relatively undisturbed. The northwestern border is much more complex which gives the area a graben-like structural configuration (Boehner, 1986).



SYMBOLS

- Geological boundary (approx or assumed)
- Fault, high angle (approx or assumed)
- Fault, low angle, teeth in direction of dip
- Diamond-drill hole, name

LEGEND

- CRETACEOUS
 - K Undivided
- CARBONIFEROUS
 - LATE
 - SV SCOTCH VILLAGE FM
 - CANSO GROUP?
 - WB WATERING BROOK FM
 - EARLY TO LATE
 - GO GREEN OAKS FM
 - EARLY
 - MR MACDONALD ROAD FM
 - CC CARROLLS CORNER FM
 - MG MEAGHERS GRANT FM
 - HORTON GROUP
 - H Undivided
- DEVONIAN
 - Granite
- CAMBRO-ORDOVICIAN
 - MEGUMA GROUP
 - Undivided

SOURCE BOEHNER, 1986



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FIGURE 7-4

GEOLOGY

SHUBENACADIE-STEWIACKE DEPOSIT

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Adjacent to the Carboniferous Highlands, very complex structural relations are evident from surface mapping and drilling. The border is interpreted as a complex fault system. Representative units from all stratigraphic levels are found in fault contact with the Horton Group rocks.

The total thickness of the Windsor Group in the Shubenacadie-Stewiacke Valley is about 760 metres. It consists of five formations as follows (starting with the youngest which overlies the pre-Carboniferous basement rocks):

Formation	Rock Type	Thickness
Gays River Formation - Macumber Formation	Dolostone	1 to 60 m
Carrolls Corner Formation	Pure anhydrite	Up to 400 m
Stewiacke Formation	Halite	Up to 300 m
MacDonald Road Formation	Cyclic carbonates, anhydrites, clastics, minor halite	162 m where present
Green Oaks Formation	Marine carbonates, clastics, minor anhydrite	143 m

Geologically, the Stewiacke Formation is considered to be one of the best salt units in Nova Scotia in regard to potential storage cavern development. It has the laterally most extensive salt section in the region and is the largest, relatively undeformed (Type A) salt deposit in the province. Twenty holes penetrated salt beds in the area, but of these only five deep holes completely penetrated the salt (153-1, 153-2, SB-1, 153-3, and 153-4). Therefore, the Stewiacke Formation is not precisely defined in regard to thickness, distribution, and composition throughout the whole area. The minimum areal extent and approximate salt thickness determined from the available intersections, however, provide sufficient data for a conceptual plan of potential salt storage cavern facility.

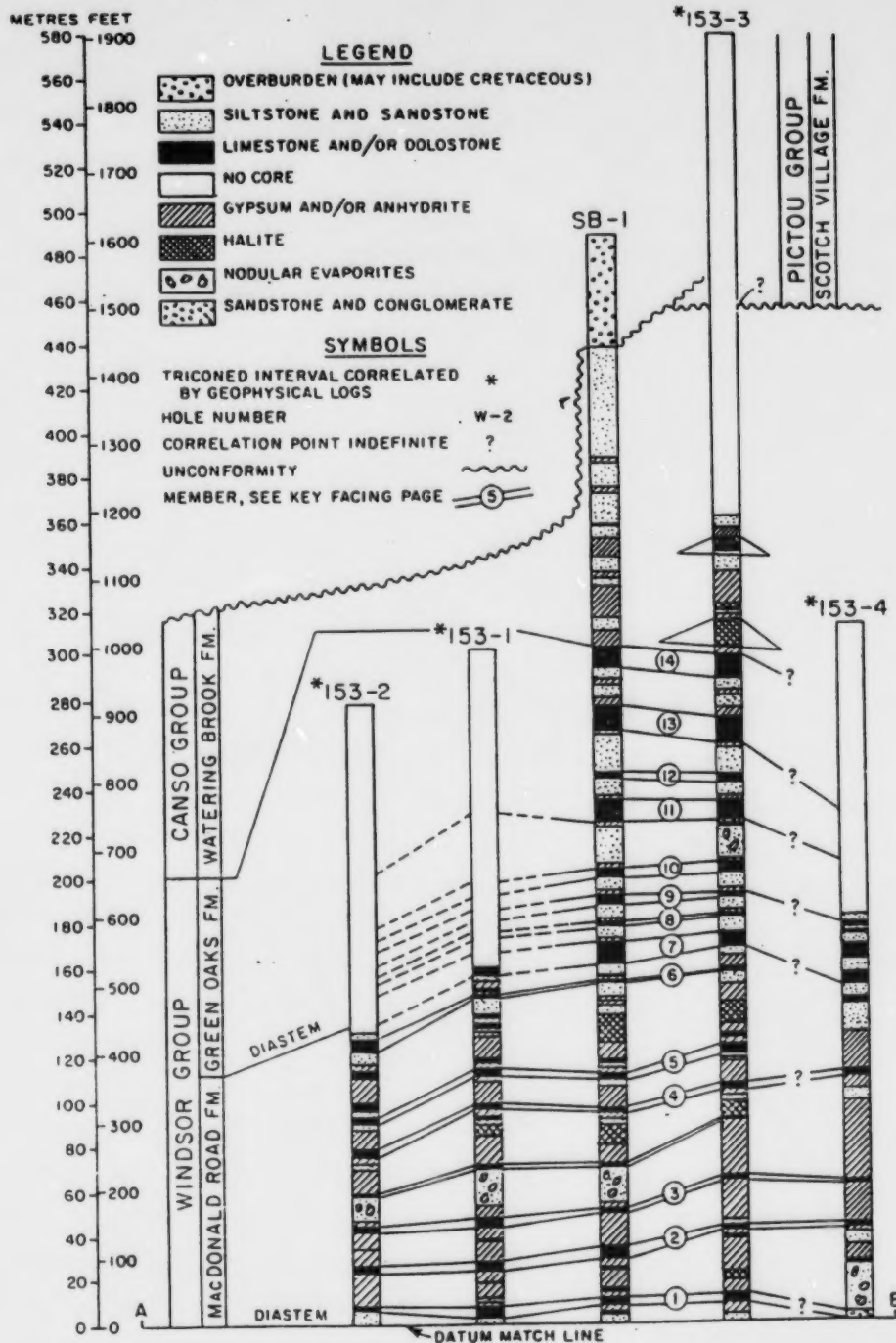
Figure 7-5 shows Boehner's (1986) stratigraphic correlation of the Windsor Group formations encountered in the Shubenacadie-Stewiacke drill holes. The halite within the Stewiacke Formation is medium to coarse-grained with abundant thin interbeds of anhydrite and green halitic siltstone. The anhydrite layers range in thickness from 1 centimetre to 5 metres, but locally attain a thickness of 20 metres. These layers of thick anhydrite would have to be defined and avoided, if possible, in locating caverns to prevent potential problems with the drill stem damage during brining.

The main block of thick salt (up to 300 metres) occurs near the centre of the basin. The depth to the top ranges from 180 to 500 metres, averaging 400 to 500 in the central (thicker salt section) part of the basin. It has a length of 40 kilometres and an average width of 6 kilometres. Figure 7-6 shows a structural contour map of the salt within the Stewiacke Formation.

The salt is stratified and only slightly deformed (except near the northwestern boundary). No salt springs are known in the area, although it is believed that some of the Upper Stewiacke Formation anhydrite and possibly salt may have been dissolved prior to deposition of the overlying MacDonald Road Formation. Some faulting is present in the overlying strata, but it is believed to be of only minor significance.

Chemical analyses indicate an average grade of 86.79 and 88.16 percent NaCl (whole rock) for the main Stewiacke Formation salt from the boreholes (Figures 7-7 and 7-8). Grades in excess of 90 percent and up to 94 percent NaCl are reported from specific sections (Boehner, 1986).

The relative purity of this deposit, its great lateral extent, and significant thickness would make it suitable for development of multiple storage cavern facilities. Crude oil and LPG could be stored at the sites. Compressed air storage may be feasible but would depend on proximity to tidal power developments or other generating sources. The required depth and thickness for natural gas storage is likely present in particular (deeper) parts of the basin, but these would have to be better defined.



SOURCE BOEHNER, 1986



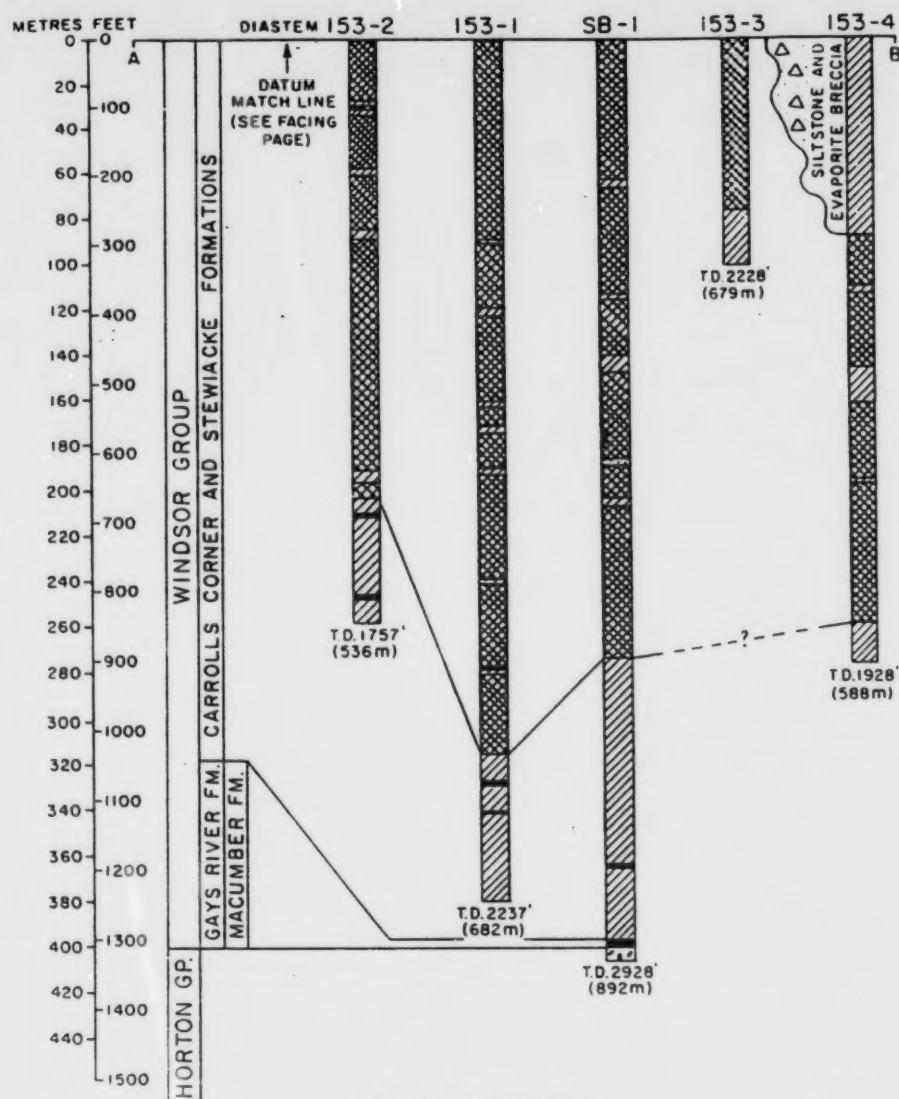
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FIGURE 7-5 a

**DRILLHOLE STRATIGRAPHIC CORRELATION
SHUBENACADIE-STEWIACKE DEPOSIT**

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KEY TO MEMBERS

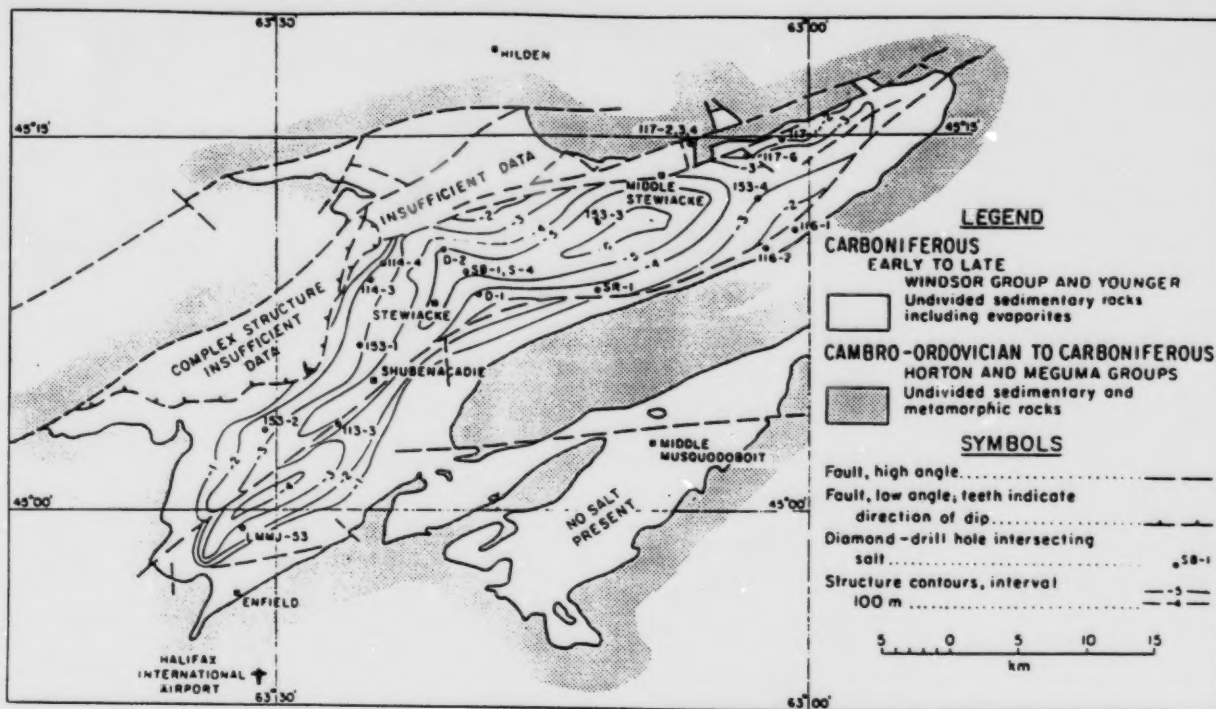
- | | |
|-----------------------------------|------------------------|
| 14 KENNETCOOK LIMESTONE MEMBER | 6 MCPHEE CORNER MEMBER |
| 13 WALLACE POINT LIMESTONE MEMBER | 5 NORTH SALEM MEMBER |
| 12 MEANDER RIVER LIMESTONE MEMBER | 4 HARDWOODLANDS MEMBER |
| 11 AVON LIMESTONE MEMBER | 3 RYAN BROOK MEMBER |
| 10 GREEN CREEK (LIMESTONE) MEMBER | 2 CLOVERDALE MEMBER |
| 9 SHUBENACADIE LIMESTONE MEMBER | 1 MOSHER ROAD MEMBER |
| 8 KENT ROAD (LIMESTONE) MEMBER | |
| 7 HERBERT RIVER LIMESTONE MEMBER | |

SOURCE BOEHNER, 1986



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FIGURE 7-5 b
(CONTINUED)



SOURCE BOEHNER, 1986

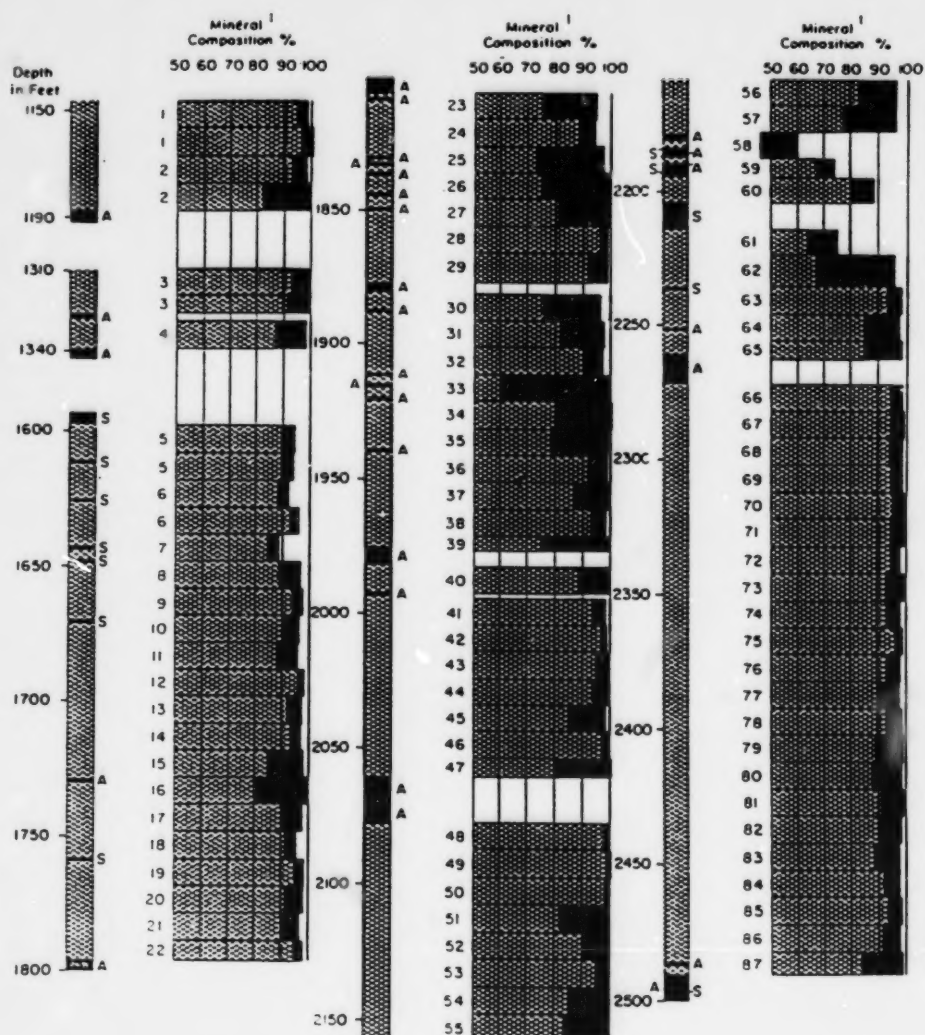


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FIGURE 7-6
STRUCTURAL CONTOUR MAP OF
STEWIACKIE FORMATION SALT

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LEGEND

Anhydrite (A)

Halite

Siltstone, Shale (S)
Variable Halite

% Halite
sample number
% Anhydrite

M.C. = Missing Core

1 Mineral composition calculated using conventional combination with NaCl based on Cl analyses and CaSO_4 based on SO_4 analyses.

2 Selected samples for analyses:
SB-1-SS1 at 2083.0' clear halite band
SB-1-SS2 at 2083.1' dark halite band
SB-1-SS3 at 1885.5' hard cube from green siltstone
SB-1-SS4 at 2495.0' anhydrite

SOURCE: BOEHNER, 1986

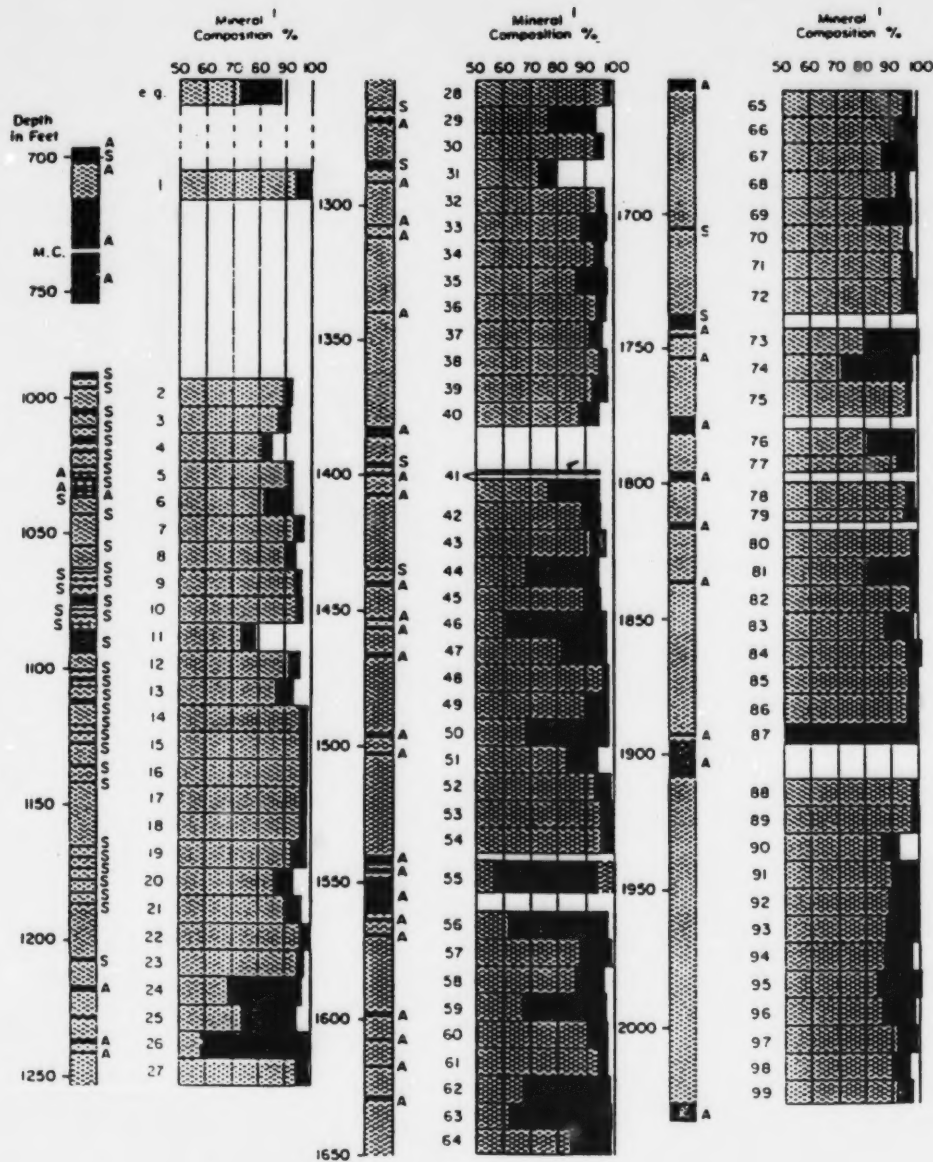


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FIGURE 7-7
PROFILES OF SALT SECTIONS IN
DRILLHOLE SB-1

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SOURCE BOEHNER, 1986



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FIGURE 7-8
PROFILES OF SALT SECTIONS IN
IN DRILLHOLE 153-1

7.4.2 Further Data Requirements

The Shubenacadie-Stewiacke salt deposit is fairly well-defined on a broad scale by drill hole data. Efforts should be now focused on site-specific evaluations and cavern size/spacing design. This would require a more closely spaced drill hole grid over an area with the thickest and highest purity salt. Rock material property tests could be carried out on samples from these and existing cores for input to engineering design of the caverns.

8.0 CUMBERLAND AREA

8.1 General

Cumberland County in northern Nova Scotia is the main salt producing area of Atlantic Canada. The first underground salt mine in Canada was established at Malagash in 1919. Currently, two deposits are being mined: Pugwash, by conventional underground room and pillar methods, and Nappan, by solution mining.

Virtually all of the salt deposits and occurrences in the Cumberland area are related to large Windsor Group diapiric structures and are found near the axes of faulted anticlines. Bouguer gravity anomalies indicate that salt is probably present throughout their length but has only been drilled and mined at relatively shallow depths to date. Deep oil drilling in certain areas has proven that salt occurs in very thick sections. Potash mineralization has been recorded in some of the areas, although not in economic quantities.

8.2 Malagash Deposits

8.2.1 Geology and Salt Cavern Implications

The first underground salt mine at Malagash was established in 1919, after the discovery of salt springs and a water well intersection of salt in the area led to exploration boreholes. Mining, engineering, and ore grade problems led to the closure of the mine in 1959 after a total of 1.46 million tons of salt had been produced. Potash was discovered in small quantities and four deep holes were drilled to the west of the Malagash Mine in 1966. Two holes intersected significant potash

mineralized zones but it was considered too deep and low grade to be mined. In 1973, a very deep (petroleum) hole was drilled in the area and encountered the Windsor Group salt zone between 2506 and 3080 metres.

The salt seams which were mined occur in a steeply dipping anticline structure, so the depth to salt progresses from about 30 to 850 metres within the former mine area. The geology of the mine is not discussed further here. Although storage in abandoned salt mines is practiced elsewhere, this particular deposit is likely not suitable because of its shallow depth, complex structural relationships, complicated geometry of mine workings, salt dissolution features, and abundance of old boreholes which may not be properly sealed. A very good summary of the mine geology is provided by Boehner (1986).

Potential for further salt resources exists in the western part of the anticline structure, west of the former mine site. Salt was encountered in both Wallace No. 1 and Wallace No. 2 at intervals of 845 to 1223 metres (No. 1), and 372 to 542 metres, and 756 to 798 metres (No. 2). However in both cases, the salt was interbedded with potash and brecciated siltstones and sandstones. These salt sections are generally either too thin or too deep for consideration of storage cavern development. Further exploration of the area may indicate better potential salt sections.

8.2.2 Further Data Requirements

Based on existing information, the salt section in the area of the mine and west of the mine would not be favourable for cavern development. The shallow salt intervals defined to date are generally too thin for consideration of crude oil or LPG storage. Potential for natural gas storage exists, but the deeper salt is at greater depth than is economically viable for cavern storage and contains abundant interbedded potash and insolubles which would lead to difficulties in cavern development. However, further deep drilling on the gravity lows in the general area may identify more pure halite sections at slightly more shallow depths.

8.3 Nappan Deposit

8.3.1 Geology and Storage Cavern Implications

The Nappan Deposit is currently being exploited by brining by Domtar Limited (Sifto Salt Division). The salt diapir was originally explored for petroleum by Imperial Oil Limited (1926 - 1932) and Sun Oil Company Limited (1945 - 1947). It was initially thought that the structure was a simple anticline (Minudie Anticline), but deep drilling of petroleum exploratory wells established that it was a dome or diapiric structure with thickened evaporites at the core.

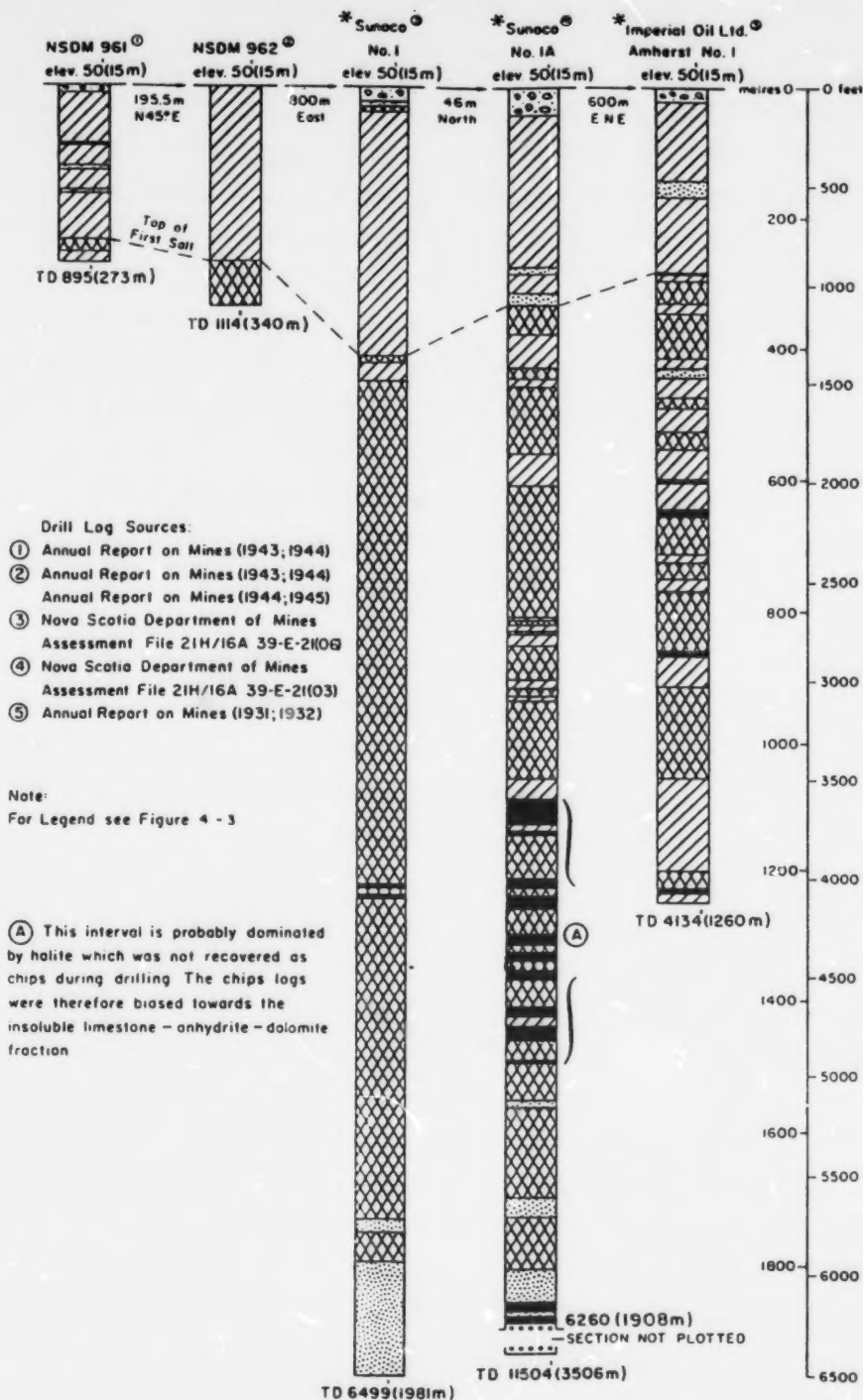
In 1947, Maritime Industries Limited took control of the previously drilled deep wells Sunoco Nos. 1 and 1A, in the Nappan area, and began salt production by solution mining. Domtar Chemicals Limited eventually took over the operation and it continues today. Figure 8-1 shows the schematic of the boreholes drilled in the area. It is to be noted that these logs were compiled based on chip samples which does not allow precise stratigraphic definition, particularly in evaporite sequences. An apparent relatively pure halite section is defined in the Sunoco holes from approximately 400 to 1800 metres. Analyses of the borehole cuttings indicate 96.6 percent NaCl at depths below 600 metres. Above this, it is less pure.

The lateral extent of the deposit is not fully defined, but the gravity data (Figure 8-2) and interpreted geology indicate it may underlie an area approximately 4.0 by 5.0 kilometres. There is no evidence of salt springs in the area, indicating that the salt is probably well sealed although karst topography is found in surface outcrops of carbonates nearby.

The depth, relative purity, and extensive thickness of the salt in this deposit would make it suitable for storage cavern development for any product. It is well situated with regard to potential development of Fundy Tidal Power, but economic factors would likely preclude hydrocarbon storage at this location.

8.3.2 Further Data Requirements

The deposit is probably large enough to accommodate caverns for more than one use and a compressed air energy cavern could be developed



Drill Log Sources:

- ① Annual Report on Mines (1943;1944)
- ② Annual Report on Mines (1943;1944)
- ③ Annual Report on Mines (1944;1945)
- ④ Nova Scotia Department of Mines
Assessment File 21H/16A 39-E-2(106)
- ⑤ Nova Scotia Department of Mines
Assessment File 21H/16A 39-E-2(103)
- ⑥ Annual Report on Mines (1931;1932)

Note:

For Legend see Figure 4 - 3

(A) This interval is probably dominated by halite which was not recovered as chips during drilling. The chips logs were therefore biased towards the insoluble limestone - anhydrite - dolomite fraction.

SOURCE BOEHNER, 1986

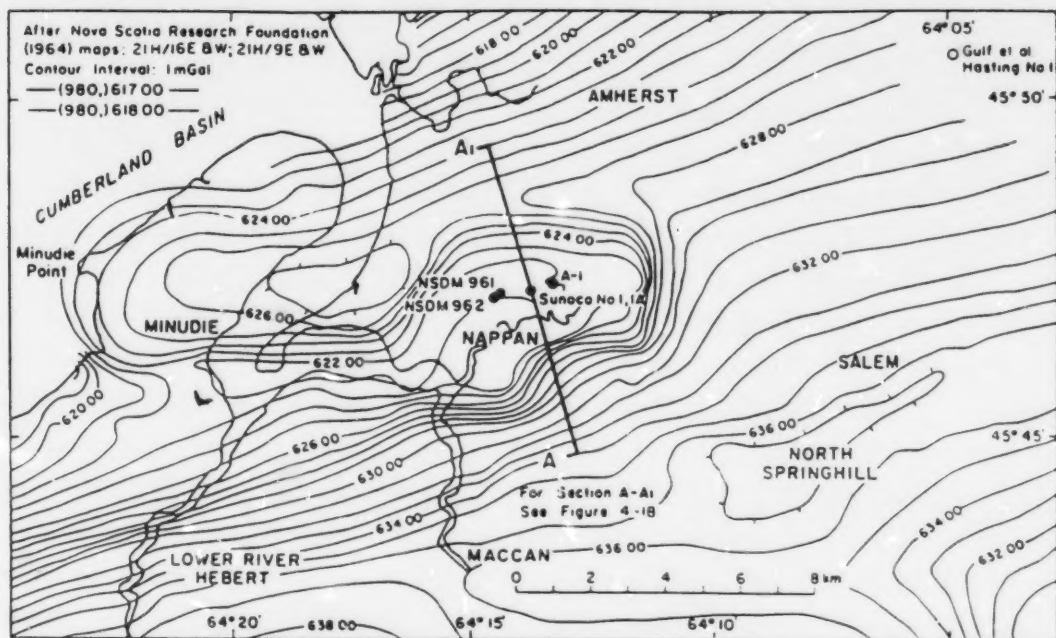


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FIGURE 8-1
DRILLHOLE PROFILES - NAPPAN DEPOSIT

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SOURCE BOEHNER, 1986



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FIGURE 8-2
BOUGUER GRAVITY ANOMALY MAP
NAPPAN DEPOSIT

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adjacent to the existing solution mining cavity operated by Domtar, allowing for a safe separation distance and long-term creep effects. Also, the long-term plans of Domtar for the existing cavities are not known - they may include eventually using it for a storage site.

Potentially suitable areas within the deposit for cavern development might be to the west of the Sunoco holes (Figure 8-2) in the area of the NSDM holes (961 and 962). These two holes only penetrated the top of the salt section. Further deep drilling in this area would establish the salt thickness, purity, stratigraphy, and structural relationships. Based on these data, the optimal intervals for cavern development would be selected.

8.4 Pugwash Deposit

8.4.1 Geology and Storage Cavern Implications

Salt was discovered at Pugwash in 1953. A shaft was sunk to a depth of 219.5 metres in 1959, and production commenced at the 192 metre level (the same year the Malagash Mine closed). It is currently mined by a modified room-and-pillar method (to avoid anhydrite layers) and operated by the Canadian Rock Salt Company Limited.

The deposit is extremely complex both structurally and stratigraphically with many contorted, near-vertical beds. Evans (1972) gives a good account of the structural and stratigraphic complexity and concludes that the Pugwash structure is intermediate between a piercement diapir and a deformed anticline. This complex configuration was not apparent in the initial drill holes and it was assumed the structure was relatively simple. The deposit is well sealed by a thick residual soil produced by dissolution and collapse of formerly exposed evaporites. An insoluble gypsum-limestone breccia also caps the evaporite core.

A detailed account of the geology of the mine is not provided here, since its presence precludes the potential development of storage cavities at least at the shallow (mining level) depths. Boehner (1986) provides a good account of the mine geology and references to other detailed studies.

Eventually, use of the underground mine for storage may be considered if it is abandoned as a producing mine due to economics.

Otherwise, the salt in the upper (mining level) part of the deposit is highly deformed with anhydrite interbeds of generally complex distribution, making storage cavern development difficult.

Seismic profiles indicate salt may extend to depths of 1500 metres. Pacific Petroleum Limited drilled a deep petroleum exploration hole (3003 metres) in 1963, 11 kilometres east of the Pugwash mine. Salt was first encountered at 2678 metres, and a total of 178 metres were intersected.

This depth would not be suitable for consideration of any of the four storage substances in this assessment. Further exploration closer to the mine site might establish good quality salt closer to the surface. However, other sites in the Cumberland area would likely be considered more favourable for technical and economic reasons as potential crude oil or LPG storage sites.

8.4.2 Further Data Requirements

Deeper drilling in the vicinity of the mine would determine whether a suitable thickness of salt is present in the intermediate zone between the upper mining level and the deep (2600+ metres) salt encountered east of the mine.

9.0 CANSO-BRAS D'OR AREA

9.1 General

Many salt springs and seeps in this area of southeastern and central Cape Breton Island have led to interest in the potential for salt and potash resources. It was not until the mid-1960's, however, that Dow Chemical Limited and Domtar Limited carried out exploration programs in the Strait of Canso area to define the salt resources. Recent potash and base metal exploration drilling by Noranda and Chevron, in addition to the work by Dow Chemical and Domtar, has defined several salt deposits in the Canso-Bras d'Or area.

Some of these deposits were planned to be exploited by solution mining and used for storage caverns for the American SPR or a trans-shipment facility. Consequently, these deposits have been relatively well-defined by drillholes and gravity surveys. Other deposits have been discovered only recently and are known only from one or two drillhole intersections.

9.2 Cleveland Deposit

9.2.1 Geology and Storage Cavern Implications

This deposit was recently discovered by Noranda Exploration Company Limited (1981). Salt was encountered in drill hole N227-2 from 732 to 1054 metres. The overlying strata consist of flat-lying to shallow-dipping, fine-grained clastics (mudstone, siltstone, shale, and fine-grained sandstone). Interbedded shale and mud breccia is the main impurity in the salt section. Traces of potash are reported (Noranda Assessment Report, 1982).

This site has potential for crude oil and LPG storage. A considerable thickness of relatively pure salt has been confirmed, and the overlying strata should provide a suitable seal for the caverns.

9.2.2 Further Data Requirements

More deep drilling would be necessary to fully define the thickness and extent of the main salt section.

9.3 Estmere Deposit

9.3.1 Geology and Storage Cavern Implications

This deposit has also been recently discovered in deep drilling (Drill Hole N227-1) by Noranda Exploration Company Limited. Drill Hole N227-1 intersected salt from 399 to 860 metres, where the hole was abandoned due to broken and stuck drilling rods (Noranda Assessment Report, 1982).

The salt is fairly massive with no potash reported. Some anhydrite and clastic layers are recorded. The depth and considerable thickness of this deposit would make it potentially suitable for storage of crude oil, LPG, compressed air and possibly natural gas if sufficient depth is defined by further exploration.

9.3.2 Further Data Requirements

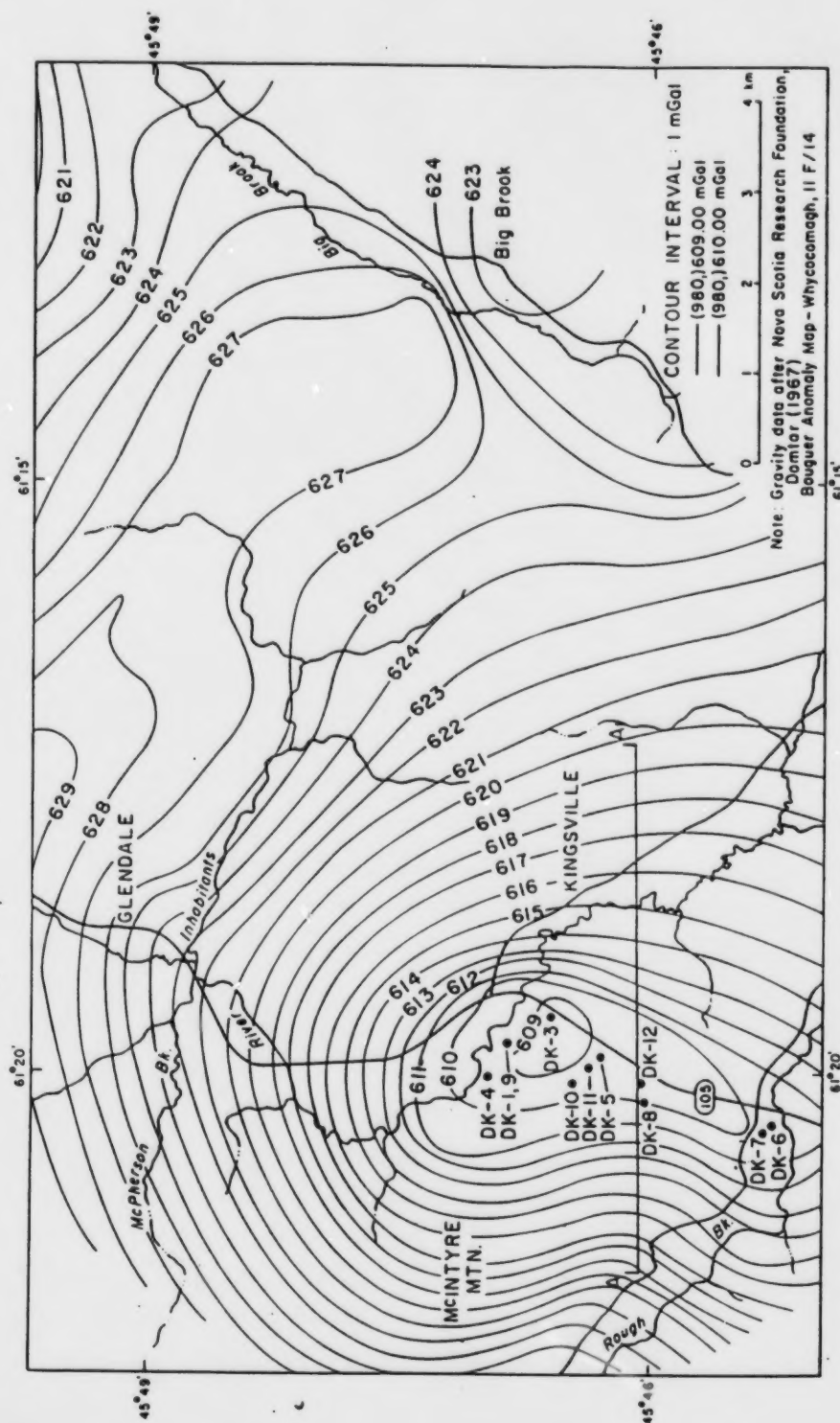
More deep drilling on the gravity anomaly would better define the available salt thickness, stratigraphy, and extent of the deposit.

9.4 Kingsville Deposit

9.4.1 Geology and Storage Cavern Implications

The Kingsville deposit was investigated for its salt and potash potential by Hayes (1931). Many salt springs were known in the general region but none in the immediate vicinity. A drilling exploration program of the Kingsville area was undertaken by Domtar between 1968 and 1971 (Domtar Incorporated, 1978). Twelve holes were drilled and all intersected significant salt sections. Proven reserves based on Domtar's work are placed at 28.6 million tonnes.

Figure 9-1 showed the Bouguer gravity anomaly and drill hole locations over the deposit. Figure 9-2 shows the drill hole logs. The deposit was interpreted as a salt-cored anticline by Domtar. Abnormal thickening and complex folding of the salt is evident from the drill logs and probably resulted from plastic flow of salt into the structured axis, triggered by the faults which bound the deposit. The central thickened part is called the "core zone salt" and its lateral extent was important to define when Domtar considered the possibility of underground mining. It is



SOURCE BOEHNER, 1986



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FIGURE 9-1
BOUGUER GRAVITY ANOMALY MAP
KINGSVILLE DEPOSITS

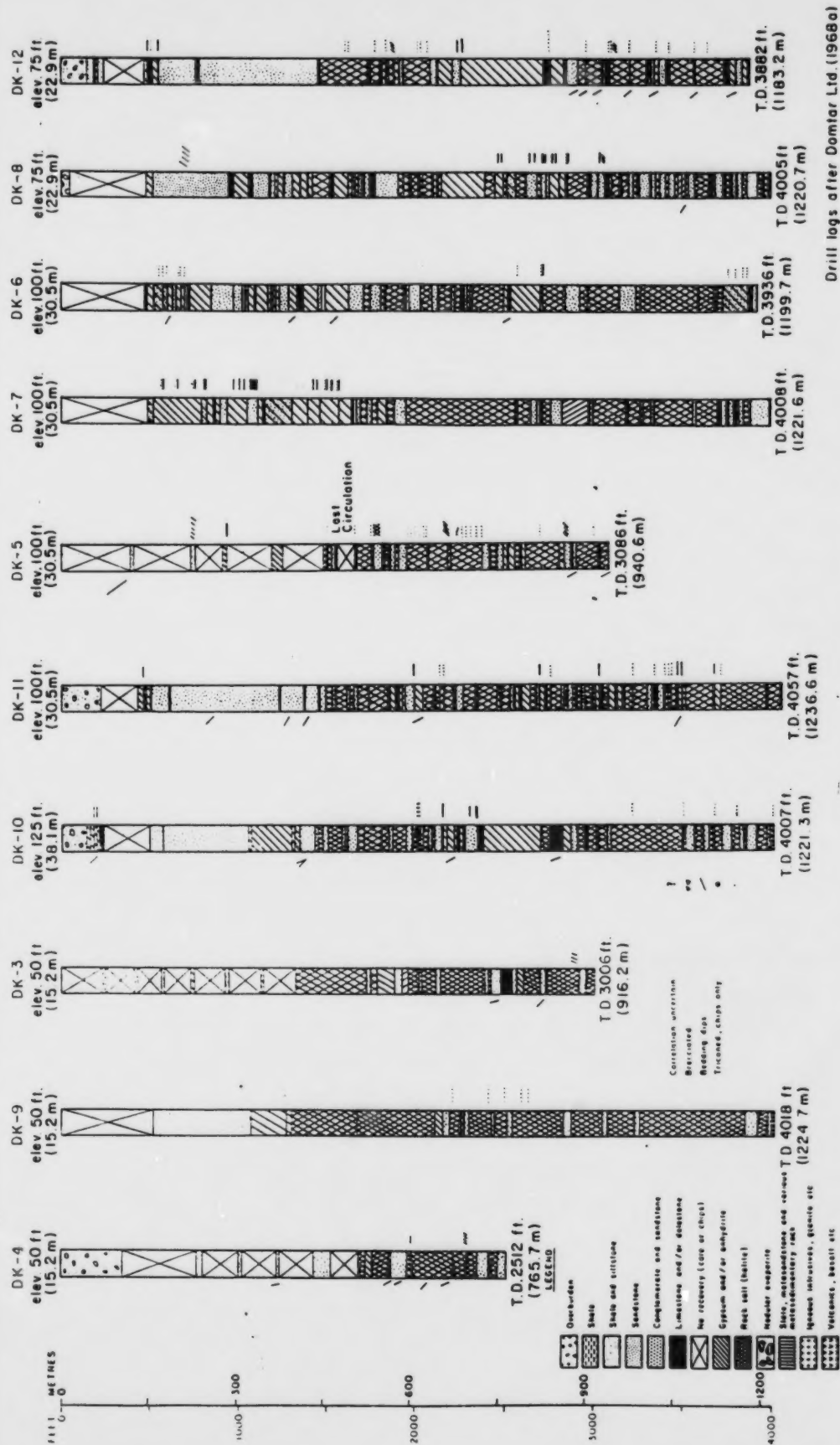


FIGURE 9-2
DRILLHOLE LOGS - KINGSVILLE DEPOSITS

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SOURCE: BOEHNER, 1986

approximately 100 metres wide at Drill Holes DK-6 and K-7. Drill Hole DK-9 also intersected core salt in the upper part of the hole (Figure 9-2).

Siltstone is the most abundant interbedded insoluble encountered in the salt sections, followed by anhydrite. The siltstone is often partly fractured and brecciated. The brecciation was probably the result of partial salt dissolution and caving of the overlying clastics. Frequently, the fractured and brecciated nature of the siltstone may be a positive factor in the development of storage cavities. The siltstone would tend to break into smaller pieces rather than large blocks during the brining, having less potential for damage to the cavern pipe.

All drillholes encountered thin beds of anhydrite throughout most of the holes. Drillholes DK-10 and DK-12 contain the thickest, continuous anhydrite sections (up to 240 metres). The dip of the anhydrite beds is generally steep (about 70 degrees), so the true thickness is probably only 60 to 70 metres (Domtar Incorporated, 1978). The anhydrite is fine-grained and massive and locally calcareous or dolomitic.

In many instances, the anhydrite is wholly or partially altered to gypsum on the top of the salt formation. This occurs as a result of groundwater circulation (relic water table) which hydrated the anhydrite to gypsum. Fine acicular crystals of anhydrite are also present in some high-grade salt sections.

Domtar considered the deposit for a potential SPR crude oil storage site. It carried out a brining test near DK-9 at the northern end of the salt body. The hole was drilled to a depth of 1220 metres and fitted with 22 centimetre production casing. The test results indicated that brining was a suitable means of extracting the salt.

This deposit is suitable for storage of all types of products under consideration. It is especially well-suited to crude oil and LPG storage because of its proximity to the Strait of Canso and access to tanker shipments (discussed in Part E).

9.4.2 Further Data Requirements

Conceptual plans for a number of storage caverns located within the best halite sections encountered in the drillholes were drafted by Domtar (1978). The cavities were designed to follow the steep dip of the

formation. Production brine cavities were outlined in every drillhole except DK-4. Drill Holes DK-6, DK-7, and DK-9 were determined to be the best holes for development of larger cavities. The purity of the salt in these holes is approximately 90 percent. The planned diameter of the caverns was 60 to 90 metres with a height of 120 and 490 metres. The initial total storage volume proposed was 10.3 million cubic metres (65 million barrels), with potential for future expansion to accommodate on the order of a hundred million cubic metres (several hundred million barrels) of storage.

The most suitable salt sections within the hole drilled by Domtar have been well-defined. Further data requirements needed to fully assess the potential of this site would include high resolution seismic, and possibly gravity surveys to better define the structural configuration of the entire deposit and provide targets for thicker, more pure salt sections. Temperature and moisture data should be collected from existing or new exploratory drillholes, as well as samples for rock mechanics testing, to provide input to cavern design.

9.5 McIntyre Lake Deposit

9.5.1 Geology and Storage Cavern Implications

The presence of a major salt deposit at McIntyre Lake was established by a drilling program in 1972 and 1974 by North Canadian Oils and Murphy Oil Company Limited. Further exploration work was conducted by Home Oil Limited in 1978 and the site was evaluated as a possible crude oil storage site for the SPR. Potential future development of a Canadian strategic reserve site and/or trans-shipment storage facility were also discussed.

Regionally, the major geological structure in the area is a large syncline, defined by the Windsor Group and overlying the Canso and Riversdale Groups. Several major faults are associated with the structure and bound the Windsor outcrop areas. The surface expression of the McIntyre Lake structure itself is interpreted as a fault-bound anticline (Boehner, 1986). Subsurface information indicates a complexly folded structural configuration, which is interpreted as a diapiric anticline similar to those in the Cumberland area (ibid.).

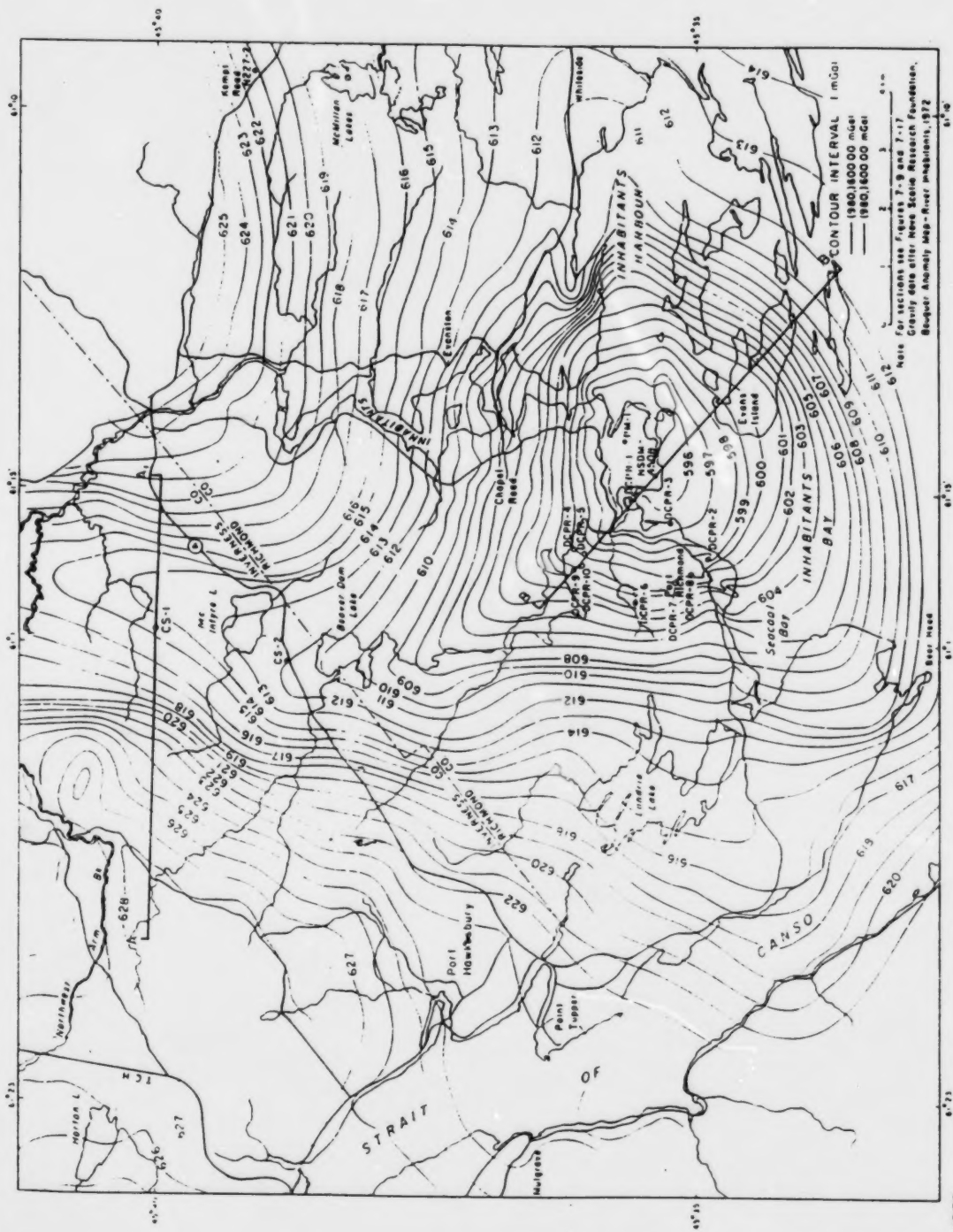
The area first attracted interest in salt potential when the NSRF gravity maps showed a negative anomaly in the area (Figure 9-3). Two exploratory holes were drilled on the gravity low by North Canadian Oils Limited (NCO) and Murphy Oil Company Limited. NCO Canso Strat No. 1 was drilled in 1972 and NCO/Murphy Oil Canso Strat No. 2, in 1974. These drillholes confirmed the presence of a large salt deposit.

NCO Strat No. 1 encountered salt at a depth of 256.6 metres (Figure 9-4). The overlying strata consisted of brecciated clay-shale, gypsum and highly permeable massive limestone intervals. The salt contains locally thick anhydrite interbeds (especially from 526.4 to 528.7 metres), some clay, and minor potash impurities. A steeply dipping dark dolostone layer was recorded from 531.5 to 562.7 metres (Home Oil Company Limited, 1978; Hale, 1972; Giles, 1981a).

Canso Strat No. 2, located about 2.2 kilometres south of No. 1 between McIntyre and Beaver Dam Lakes, was drilled in 1974. Salt was first encountered at a depth of 254.8 metres, overlain by gypsum, clay, shale, and limestone (locally brecciated). The salt varies from being relatively clean to being very impure with numerous zones (up to 20 or 25 metres thick) of anhydrite, claystone, and limestone (Hale, 1974). Figure 9-5 shows the drill hole profiles for Canso Strat No. 2. Dips in both holes are steep (generally 50 to 90 degrees overall and 60 to 70 degrees within the main salt).

Although a simple linear correlation between the two holes was attempted by NCO/Murphy Oil, it is apparent that very complex structural and stratigraphic conditions exist between the two holes, making stratigraphic correlation very difficult (Giles, 1981a). Two fault or shear zones were reported from Canso Strat No. 2 at 559 to 559.9 metres and 898 metres.

The salt is variably pure (80 to 95 percent), averaging 85 percent NaCl. Potash is a minor constituent, generally less than 0.1 percent potassium. The cavernous limestone encountered in Canso Strat No. 1 is a concern regarding adequate sealing of the casing and potential leaks in the cavern. This is most important in relation to compressed air and natural gas, however, and the deposit may not have the required depth and thickness of salt for these storage substances. This site has good



SOURCE BOEHNER, 1986



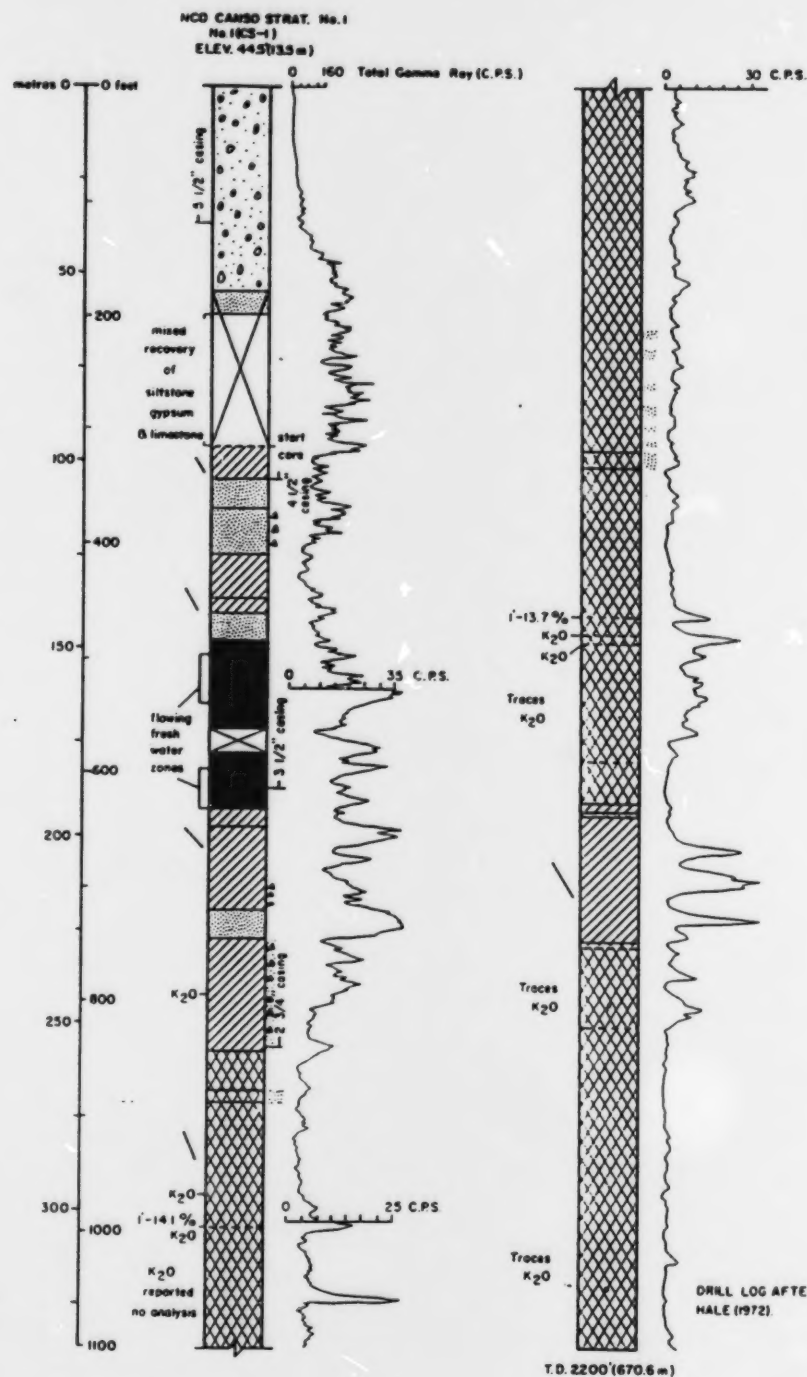
NOLAN, DAVIS
& ASSOCIATES

FIGURE 9-3

BOUGUER GRAVITY ANOMALY MAP MCINTYRE LAKE & RICHMOND DEPOSITS

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SOURCE BOEHNER, 1986



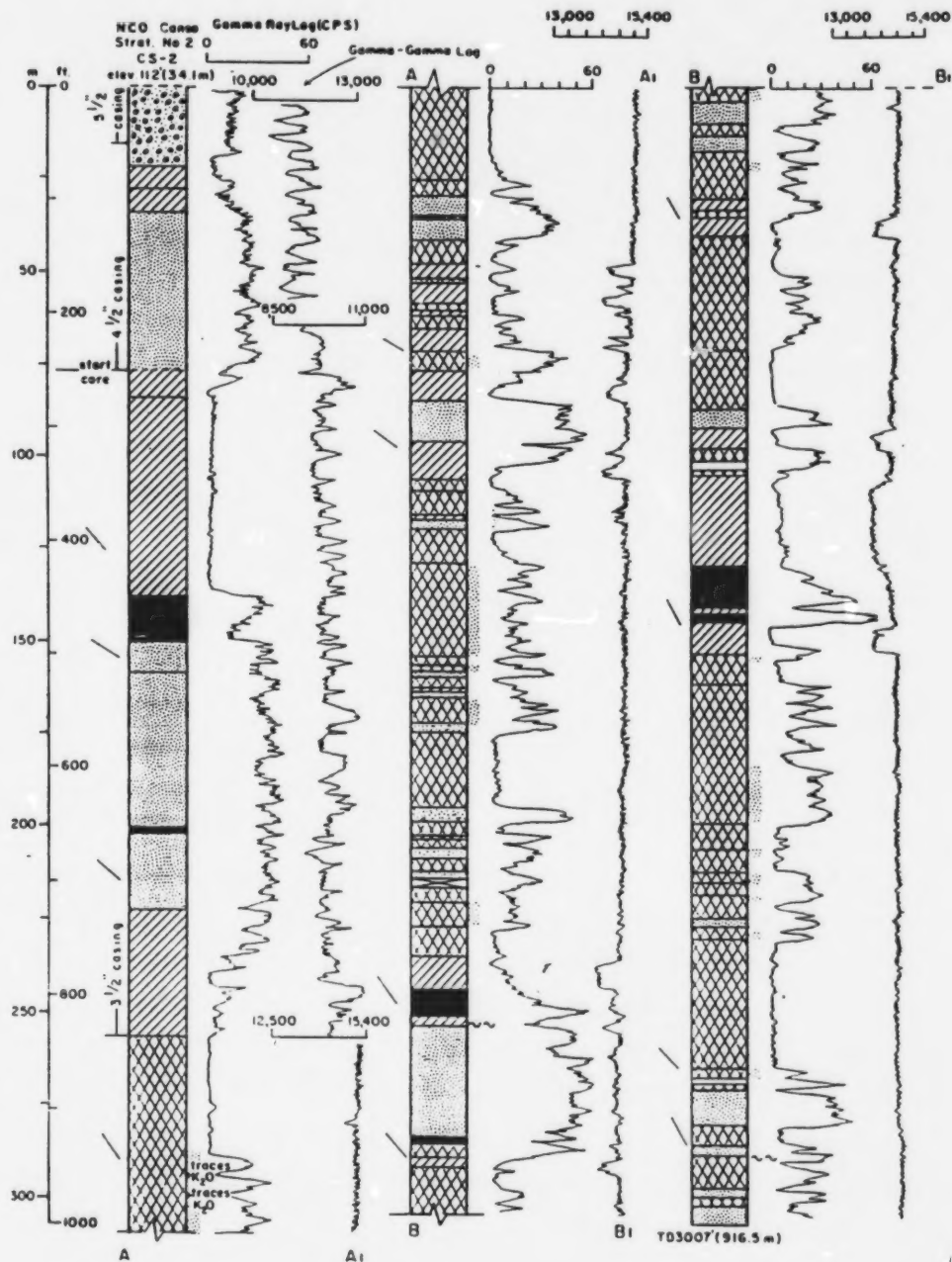
**NOLAN, DAVIS
& ASSOCIATES**

FIGURE 9-4

**DRILLHOLE LOG-CANSO STRAT. NO. 1
McINTYRE LAKE DEPOSIT**

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potential for storage of crude oil and/or LPG. It was considered by the Home Oil Consortium as a potential SPR site or Canadian strategic reserve and possible trans-shipment site because of its proximity to the deep water port at the Strait of Canso, capable of handling VLCC ships (very large crude carriers) and tankers.

9.5.2 Further Data Requirements

More deep drilling on the deposit is required to understand the complex structural and stratigraphic configuration. Down-hole geophysical logging (density and gamma ray logs) would aid in the correlation of boreholes. Deeper drilling is required to define the full thickness and purity of the salt section(s). High resolution seismic surveys would help define the structural configuration and would potentially provide drilling targets (high quality halite folds).

9.6 Malagawatch Deposit

9.6.1 Geology and Storage Cavern Implications

The Malagawatch salt deposit was discovered initially in a deep hole drilled by Chevron Standard Limited and Irving Oil Company Limited on a petroleum prospect. A significant section of salt and potash was intersected in a hole near Malagawatch Point. This led to a potash exploration program in the area by Chevron Standard Limited and Noranda Exploration Company Limited.

Chevron-Irving Malagawatch No. 1 intersected salt at 231 metres and was drilled to a total depth of 560 metres. Halite mixed with mudstone and anhydrite were encountered in this interval, with a significant potash section at 487 to 572 metres (Dekker, 1982).

A second hole was drilled 18 metres west of the initial hole in order to fully core the potash zone. Potash was present intermittently from 463 metres to a depth of 525 metres. A potash drilling program followed. Extensive gravity, marine seismic and vibroseis surveys were carried on simultaneously with the drilling program. A total of nine holes were drilled to depths ranging up to 1221 metres. The total depth drilled was 9187 metres.

The drilling program revealed a complicated stratigraphy and structure for the deposit. Most units were assigned to the base of the Upper Windsor Group or the lower Windsor Group - A and B subzones (Dekker, 1985). Figure 9-6 shows the interpreted composite stratigraphy of the Windsor Group at Malagawatch. The "A" subzone consists of fairly uniform, massive grey halite with interbedded anhydrite and mudstone, grading up into a brecciated darker grey and orange-brown halite. This is the main section of interest for potential storage cavern development. The presence of a thick anhydrite section below the grey salt is inferred from regional drill information (Dekker, 1985). The overlying rocks of the "B" subzone consist of these depositional cycles of mudstone and siltstone overlain by carbonate followed by anhydrite and more halite.

A confirmed thickness of 329 metres of relatively clean halite is present at the Malagawatch site. It has potential for development of crude oil and LPG storage and would be more favourable if thicker salt sections were proven.

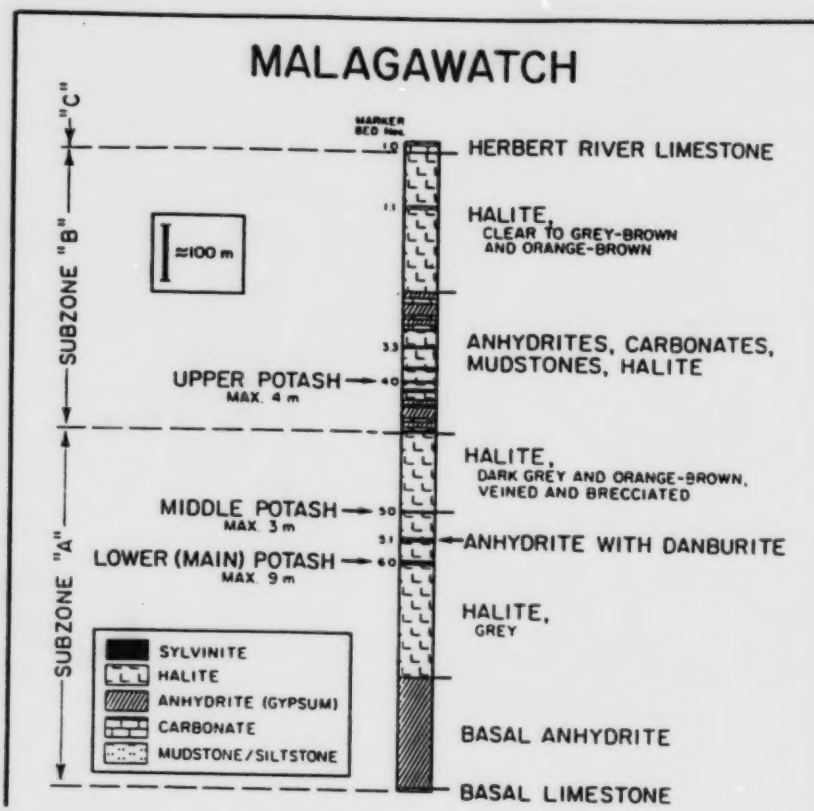
9.6.2 Further Data Requirements

The deposit is fairly well known from the Chevron potash exploration program. Further examination of the core from these holes, along with the geophysical logs and surface gravity and geophysical surveys could be used to delineate the best potential location and interval for development of salt caverns. Further test drilling would then be required to fill in the data gaps between the previous drill holes and to refine the interpretation of the complex structure and stratigraphy at the site.

9.7 Orangedale Deposit

9.7.1 Geology and Storage Cavern Implications

Noranda Exploration Company Limited drilled an exploration hole (N225-1) after initial geophysical and geochemical surveys indicated anomalies in the area. A highly brecciated salt was encountered roughly between 610 and 892 metres. Four additional holes were drilled on the gravity low following reports of significant potash intersections at Malagawatch by Chevron and Irving Oil Limited. Figure 9-7 shows the Bouguer anomaly map and location of drill holes.



Composite stratigraphy of the Lower Windsor Group.

SOURCE DEKKER, 1985



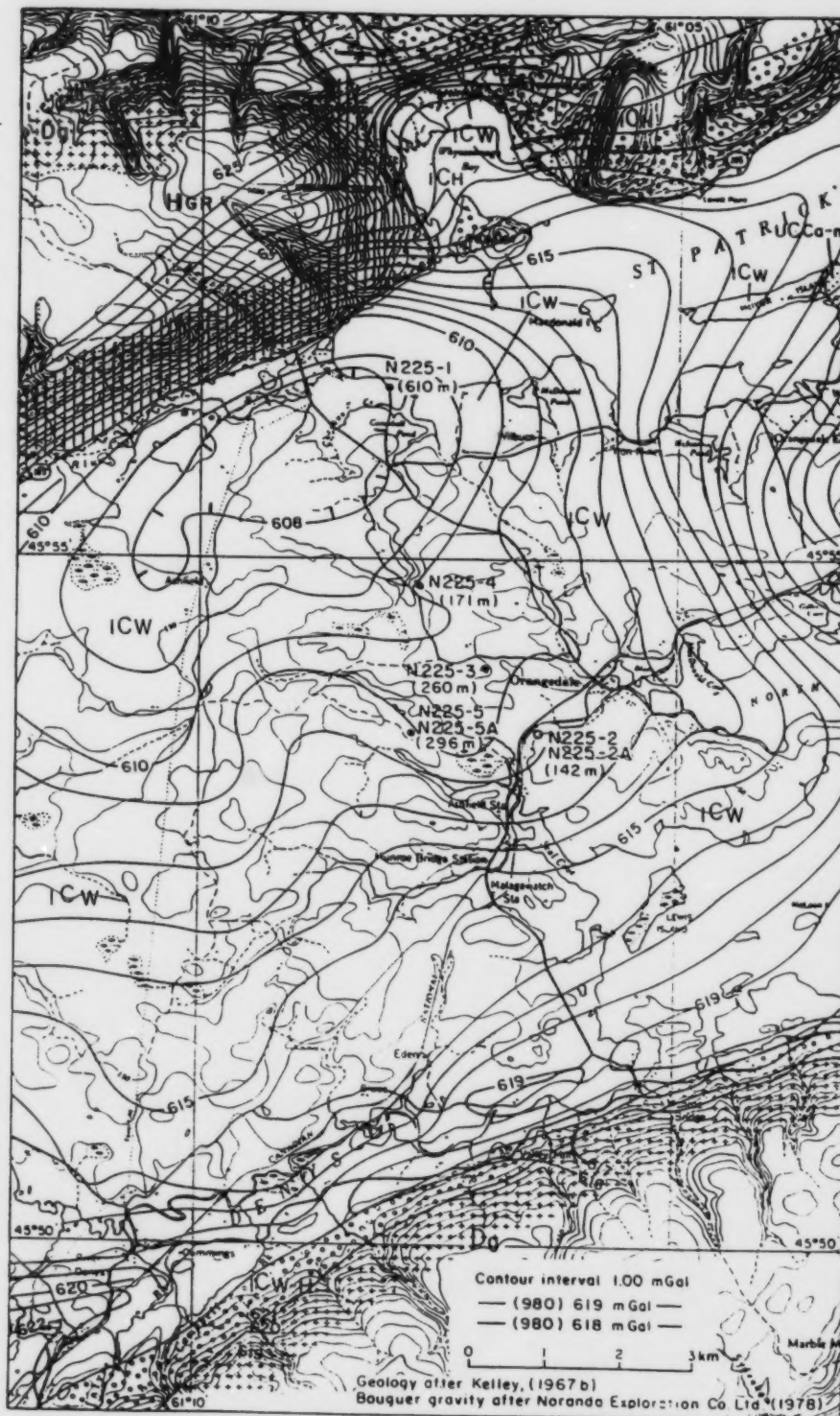
NOLAN, DAVIS
& ASSOCIATES

FIGURE 9-6

COMPOSITE STRATIGRAPHY - MALAGAWATCH

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SOURCE: BOEHNER, 1988



**NOLAN, DAVIS
& ASSOCIATES**

FIGURE 9-7

**BOUGUER GRAVITY ANOMALY MAP &
DRILLHOLE LOCATION-ORANGEDALE DEPOSIT**

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The Windsor sediments in the area consist of cyclic interbedded carbonates, sulphates, halite, and fine-grained clastics. All cycles do not have salt sections, but every cycle ends with the disruption of evaporite sedimentation and deposition of fine clastics (siltstone and mudstone). Four out of five holes intersected salt. The depth to the top of the salt is irregular (approximately 170 to 550 metres). Minor potash mineralization is frequent, with "significant" intersections found only in drillholes 225-3 and 225-5A (Noranda Exploration Company Limited, 1983).

These two drillholes also have the thickest and purest salt sections of the 5 holes drilled. The main impurities are interbedded saline mudstone and clay, and anhydrite (nodules and beds) with minor limestone. The stratigraphy and structure of the deposit is broadly similar to the deposit at Malagawatch. It contains both ductile and brittle folds, and northwesterly striking, steeply dipping shear zones, inferred to be related to basement faults from aeromagnetic data.

9.7.2 Further Data Requirements

The deposit has the potential for development of crude oil and LPG storage, but the total salt thickness needs to be established. Deeper drilling in areas interpreted to contain the thicker salt sections from detailed (grid) geophysical surveys, coupled with correlation of previous drill holes, would provide more relevant information.

9.8 Port Richmond Deposit

9.8.1 Geology and Storage Cavern Implications

Exploration at Port Richmond was initiated by Dow Chemical Company of Canada Limited and Dew Mining Corporation Limited in 1967, following the delineation of a high-amplitude negative Bouguer gravity anomaly by the Nova Scotia Research Foundation.

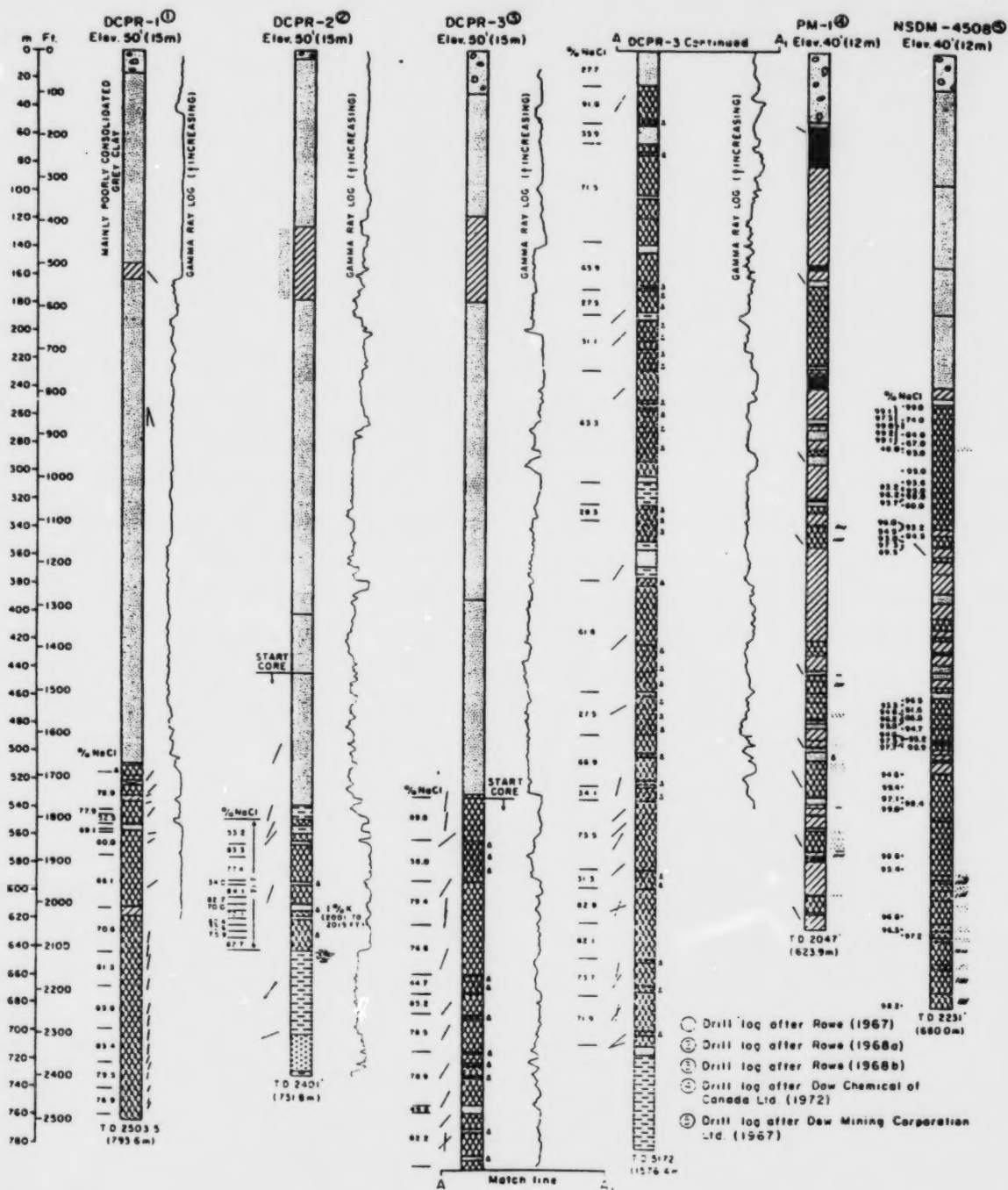
Dow drilled two diamond-drillholes and carried out subsequent detailed gravity surveys. Five deep exploration holes intersecting significant salt sections and seven shallow holes designed to obtain structural and stratigraphic information were then drilled. Two brining wells were initiated and caverns developed at the best salt intervals indicated from previous drill hole data. The Windsor Group outcrop in the

area indicates a triangular, fault-bound configuration. The largest part of the structure underlies Inhabitants Bay and Inhabitants Harbour. Port Richmond No. 1 and No. 2 were drilled in 1967 near the centre of the gravity low (Figure 9-3). PR No. 1 intersected salt at 508 metres and did not completely penetrate it at the total depth of 763 metres. PR No. 2 intersected salt from 549 to 643 metres, underlain by black shale, quartzite and conglomerate (tentatively interpreted to be the Horton Group). Steep dips (45 to 75 degrees) are reported in this hole and intervals of shale and salt-shale breccia occur within the main salt unit.

Dew Mining Corporation Limited drilled NSDM 4508 (Figure 9-3) in 1967 as well and encountered salt from 349.6 to 678.9 metres, but did not fully penetrate it. The main impurities were scattered bands of shale anhydrites and thin limestone. DCPR-3 was drilled by Dow Chemical in 1968 and intersected salt at 528 metres, and ended in salt-veined siltstone at a total depth of 1576 metres. Frequent interbeds of siltstone, shale, salt-shale breccia, and trace potash were encountered. Dips of 45 to 80 degrees are reported. Much of the salt is orange in colour which is indicative of structurally disturbed salt in other areas of the province (Boehner, 1986). A breccia interval with trace carnallite at 760 metres is interpreted as a fault zone. One more deep well, Port Malcolm (PM-1), was drilled in 1972 and encountered thin salt intervals from 282.4 to 624.0 metres. The logs of all of these deep holes are shown in Figure 9-8.

A series of seven shallow holes were drilled by Dow Chemical in 1970 to obtain better definition of the complicated stratigraphy and structure of the deposit. No evaporites were encountered (except for thin veins) and the strata are interpreted to belong to the Canso and Riversdale Groups and possibly some of the Windsor Group.

Plans to produce underground storage caverns at the site were underway in 1973 with the drilling of CDPR-11P, a brining well at the site of PR No. 1. This well was drilled to a total depth of 1227 metres and three zones were identified as suitable for cavern development: (1) 578.2 to 673.3 metres, (2) 784.3 to 837.0 metres, and (3) 857.1 to 907.7 metres. Brining of Zone (3) of this well began in 1973, but it became apparent that the required capacity could not be attained at this site, so further work was deferred.



SOURCE: BOEHNER, 1986.



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FIGURE 9-8
DRILLHOLE LOGS
PORT RICHMOND DEPOSIT

A second well (DCPR-12P) was drilled in 1975, 300 metres west of DCPR-11P. Two favourable zones were identified in this hole as follows: (1) 484.6 to 535.2 metres, and (2) 675.4 to 752.2 metres. Brining of Zone (2) in the second well was attempted in July of 1975, but problems with unpredictable, insoluble layers were encountered. It became evident that there was no identifiable correlation between the two holes even though they were only 300 metres apart, attesting to the very complex structure of the deposit.

Significant sections of salt, in excess of 100 metres, have been defined by drilling in the Port Richmond deposit. The lack of salt springs in the area suggests that the salt is well sealed. Relatively thick sections of pure salt have been defined but are difficult to delineate because of the complex structure and stratigraphy.

The depth to the top of the salt is variable but averages 500 to 550 metres, making it ideal for the entire range of potential underground storage products. With the large salt thickness available, natural gas caverns could be located at the required depths.

9.8.2 Further Data Requirements

A very large salt mass is available for the development of cavern storage space at the Port Richmond deposit. However, the most favourable locations and depth intervals will have to be carefully planned based on the previous experience of Dow Chemical. Closely spaced grid surveys of high resolution seismic and gravity are recommended, followed by a more detailed drilling program based on geophysical targets and stratigraphic interpretation.

9.9 St. Patricks Channel Deposit

9.9.1 Geology and Storage Cavern Implications

Salt has recently been discovered in one drill hole at St. Patricks Channel by Chevron Standard Limited, as part of their potash exploration program. The salt section was encountered from 396.5 to 1174.0 metres with minor associated potash reported. The deposit is apparently similar in character to the other complexly folded and deformed (Type C) deposits in this area of central-southeast Cape Breton.

The significant salt section and relative purity suggest that this deposit may be suitable for LPG, natural gas storage, and/or crude oil storage.

9.9.2 Further Data Requirements

Further site geophysical surveys and target drilling are required to define the extent of the deposit, available thickness, and stratigraphy (amount and extent of interbedded insolubles). Detailed assessment of the overlying strata is required to identify possible highly permeable layers of limestone which are suggested by the karst topography in the area.

10.0 SYDNEY AREA

10.1 General

The Carboniferous geology of the Sydney area has been extensively studied in relation to the coal resources of the region, but very little attention has been focused on the salt potential to date.

A consultants study (L.H. Cole and W.A. Bell) for Morton Chemical of Canada Limited was carried out to assess the salt and potash potential of the East Bay area in 1961 and 1962. A salt occurrence was defined by drilling in this area, but it is not considered economic as it is presently known. However, the area has some potential for further exploration.

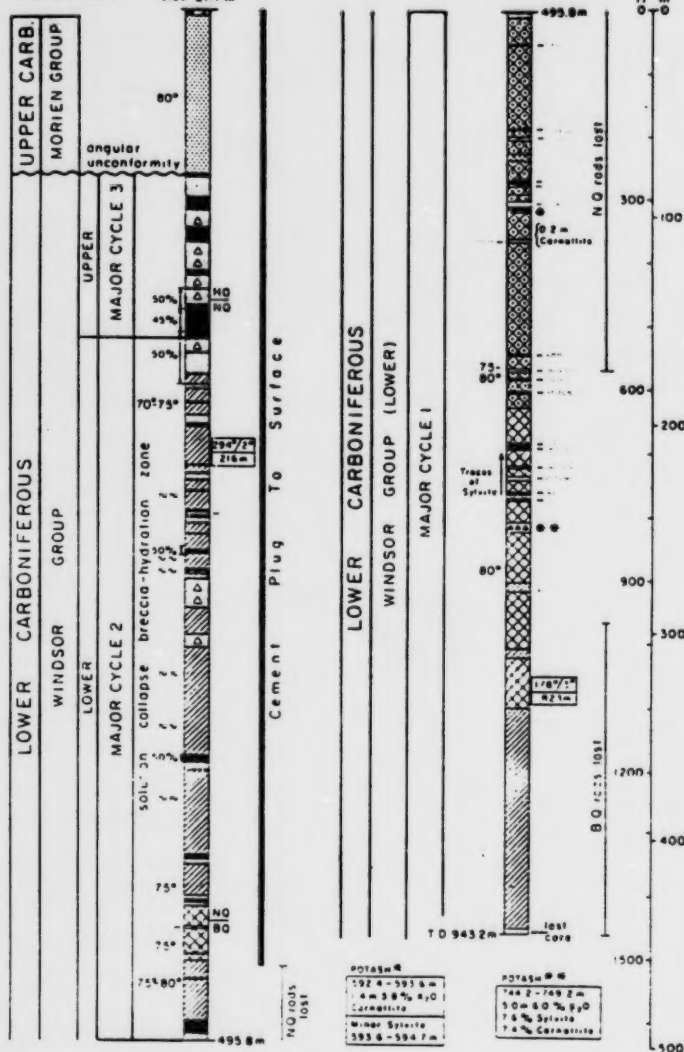
A significant salt deposit has recently been defined in a stratigraphic test hole drilled for the Nova Scotia Department of Mines and Energy (NSDME) in the Boularderie area. Potential for more salt deposits in the deeper parts of the Sydney Basin is indicated by the presence of this deposit-which was not anticipated to occur within the syncline structure in which it was found.

10.2 Boularderie Deposit

10.2.1 Geology and Storage Cavern Implications

This deposit was discovered in a stratigraphic test hole (Figure 10-1) drilled by NSDME in 1984 (Kempton Head 84-1). The location and regional geology are shown in Figure 10-2. The drill hole is located near the apex of the Boularderie Syncline, which plunges gently northeastward.

NSDME
Lat 46°04'35" N Kempt Head 84-1
Long 60°38'35" W
elevation 27.7 m



- LEGEND**
- Overburden
 - Sandstone, siltstone, mudstone (predominantly red)
 - Sandstone, grey, grey brown
 - Limestone, dolostone, variably silty and fossiliferous
 - Anhydrite, gypsum
 - Halite (± anhydrite)
 - Halite (± mudstone)
 - Potash (carnallite-halite ± minor sylvite)

Breccia

Tropeo Test - Magnetic azimuth / deviation from vertical (0°)

Depth

Shear, fracture, fault

Bedding dips measured with respect to the core axis

Core size reduction

Core recovery (50%)

Actual K₂O values are probably double the reported analysis due to extensive leaching of carnallite by the KCl - NaCl saturated drill water (not saturated for carnallite)

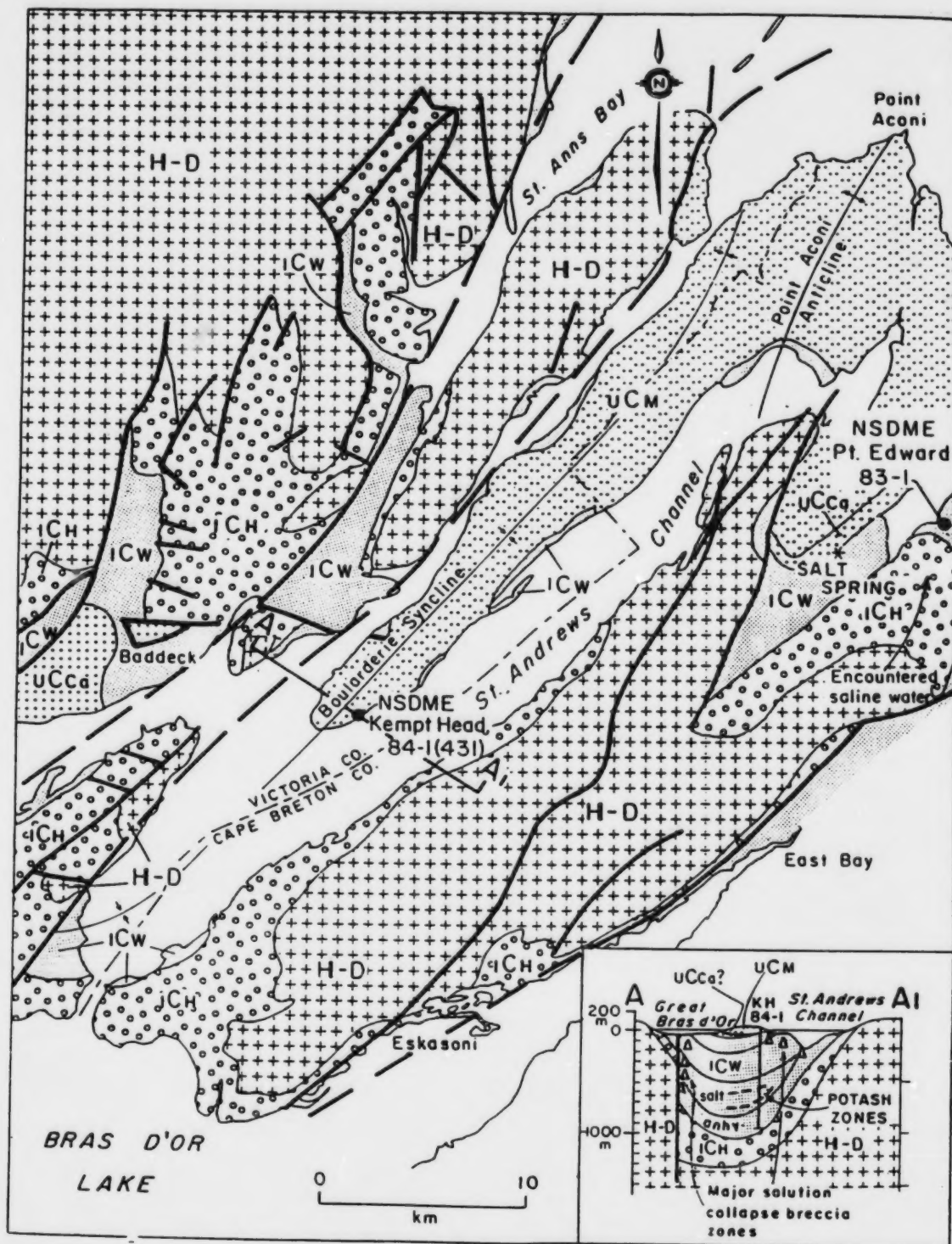
Drillhole profile, Nova Scotia Department of Mines and Energy Kempt Head 84-1, Kempt Head deposit, Cape Breton.

SOURCE: BOEHNER, 1986



NOLAN, DAVIS
& ASSOCIATES

FIGURE 10-1
DRILLHOLE LOG - KEMPT HEAD 84-1



SOURCE: BOEHNER, 1986.



**NOLAN, DAVIS
& ASSOCIATES**

FIGURE 10-2
GEOLOGY AND DRILLHOLE PROFILE
BOULARDERIE DEPOSIT

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Its northwest boundary is a fault contact. The surficial expression of the syncline is defined by the Late Carboniferous Morien Group, but the synclinal structure is inferred to extend into the underlying Windsor Group.

A very deep, elongated trough underlying St. Patricks Channel and into Great Bras d'Or Lake is inferred to be a solution trench formed by karst action and solution collapse of Windsor evaporites on the southwestern limb of the Boularderie Syncline (Boehner, 1986).

Relatively undisturbed, stratified salt was encountered at 431.2 to 457.8 metres in Kempt Head 84-1 and the Major Cycle 1 salt from 495.8 to 832.9 metres, with dips ranging from 10 to 25 degrees (Figure 10-1). Above 687 metres, the salt is low grade (less than 70 percent NaCl), whereas below this level it is quite pure (90 to 95 percent NaCl). Two potash zones were intersected at 592.2 to 593.6 metres and 744.2 to 749.2 metres. These potash zones are similar to the A subzone (Major Cycle 1) potash found at Malagawatch and Orangedale. The structural geology at Boularderie is much less complex, however, and it is classified as a structural Type A deposit.

The Boularderie Deposit, as presently known, represents a significant salt thickness of relatively high purity. Its lateral extent is not known. It has good potential for development of LPG, crude oil, and compressed air storage caverns. Natural gas storage may be suitable as well, if slightly greater salt depths are delineated.

10.2.2 Further Data Requirements

Further deep drilling on the Boularderie Syncline as well as detailed gravity surveys and high resolution seismics are required to define the stratigraphy, thickness, and lateral extent of the salt section(s).



PART D

ENVIRONMENTAL CONSIDERATIONS

PART D: ENVIRONMENTAL CONSIDERATIONS

11.0 ENVIRONMENTAL ASPECTS OF CONSTRUCTION, OPERATION, AND DISPOSAL

11.1 Introduction

Environmental impacts associated with the development of salt cavern storage can be subdivided into those associated with components of the storage system; 1) the storage site itself, 2) the stored-substance distribution system, 3) the water supply system, 4) the brine disposal system, 5) the blanket system, and 6) the initial storage filling system (Craven and Tolbert, 1977).

The storage site system comprises the salt caverns, the boreholes into the caverns, and the central pumping facility with injection pumps.

The stored-substance distribution system is composed of the equipment required to move the substance being stored in the caverns. It may consist of docks, transfer tanks, ballast treatment facilities, and pipelines to the storage site.

The water supply system consists of the equipment required to supply the water that will be pumped into the salt cavern to create the cavern and (if applicable) to remove the stored substance by means of displacement. The source of water may be wells, the ocean, lakes, or rivers. The water supply system includes the pipelines, pumps, and wells which may be required.

The brine disposal system is the system required to dispose of the brine created when the cavern is developed and the brine created by using water to displace the fluid stored in the cavern. Typically, this will include a surge pond or holding pond, brine disposal pipelines, pumps, and deep injection wells for disposal in the ground or diffuser ports for ocean disposal.

The blanket system consists of the equipment required to store and handle the material used to blanket or protect the cavity roof during cavern development. The system includes tanks, pipelines, and pumps.

The initial storage filling system consists of the equipment required to initially fill the cavern. In the case of compressed air, this would include equipment such as compressors.

11.2 Storage Site System

11.2.1 Site Construction/Drilling

The environmental impacts that may accompany the construction of the storage site are those associated with major construction activity involving appreciable earth moving operations. This will include construction of roads, building foundations, wellhead pads, and dyke enclosures. Wells will also have to be drilled into the salt body.

The construction will result in increased soil erosion with a corresponding potential increase in suspended solids in bodies of water on and adjacent to the storage site. Soil erosion can be minimized by conducting construction during the summer season when rainfall is at a minimum and constructing where the slope is at a minimum. Drainage ditches with settling ponds can be designed to prevent siltation in bodies of water receiving site surface water drainage.

During construction a portion of the land will be disturbed, surface drainage patterns will be changed, and there may be a loss of habitat for wildlife. Prior to selection of the construction site for a given deposit, studies can be done to determine if clearing the property will result in the loss of a unique wildlife habitat or a waterfowl breeding area (see Appendix C for site-specific information). As well, impacts from noise and exhaust from the equipment in use during construction can be assessed and mitigated if necessary.

There is potential for surface and groundwater impacts from the construction activities, including drawdown of the water table and quality implications associated with drilling. However, the bentonite mud used in drilling usually seals the bottom and sides of the sump. The drill cuttings can be disposed of in the sumps and the liquid can be removed and reused in the drilling operations as makeup water or diluted with seawater and disposed of through the brine diffuser (Section 11.5.2).

Brine losses may occur during drilling. This occurred in deposits at the 60 to 90 metre depth during the drilling at Port Richmond (Montreal Engineering Company Limited, 1979, p. 4-6). Such losses may result in salt contamination of the shallow groundwater on the site, and must be controlled using appropriate casing, grouting and mud system engineering techniques.

11.2.2 Operation

Once operational, roads, building foundations, wellhead pads, and dyke enclosures are not expected to have major impacts on the environment. Septic waste will need to be disposed of in on site sewage disposal systems. Solid waste will have to be collected and sent to an approved landfill disposal site.

11.2.3 Subsidence

Without a properly engineered supporting "roof" of rock salt, there is a potential for the collapse of the overlying rock and the creation of a sinkhole, with numerous possible ensuing problems. Subsidence caused by pumping brine from relatively shallow salt works in England dates back to the 1790's (Wallwork, 1973). An example of such a collapse, the Blue Ridge salt dome in Fort Bend County, Texas, has been described by Hanna (1953). In April 1976, a sinkhole developed over the Texas dome of Grand Saline. This may have been the result of a "brine pocket" forming near the top of the dome during an early period of brine production (Martinez and Thoms, 1977). Failure has also occurred at the Choctaw Dome in Iberville Parish, Louisiana. It is speculated that this collapse was caused by mining too near the top of the salt dome's cap rock. Modern solution mining techniques now maintain a sufficient thickness (determined on the basis of rock mechanics analyses) over the cavity so as to prevent its collapse.

11.3 Stored-Substance Distribution System

11.3.1 Construction

The stored-substance distribution system may consist of docks, transfer tanks, ballast treatment facilities, and pipelines to the storage site.

In the event that the substance to be stored is delivered by ship, there are potential environmental impacts associated with a spill at sea. The Home Oil Company Limited and Gulf Canada Limited (1979) report on the impacts of utilizing salt deposits at McIntyre Lake and Kingsville indicated that, in the Strait of Canso, the probability of collision of a 300,000 tonne tanker is 1.79×10^{-5} . It was estimated that there was a 64

percent probability that the tanker fleet supplying oil to the Home Oil/Domtar sites would be involved in a pollution "incident" (not necessarily significant) during the 20 year period with a probable average outflow of 270 tonnes (Home Oil Company Limited and Gulf Canada Limited, 1979).

Vessels arriving to load a liquid substance may discharge (clean) ballast water ashore. Ballast water may comprise 40 to 50 percent of a vessel's capacity. This ballast water can be pumped into the salt cavern to aid in displacement of the stored substance.

Dredging for dock construction may result in increased turbidity, increased aquatic nutrients, and the depression of oxygen levels and/or the release of toxic substances contained within bottom sediments (Craven and Tolbert, 1977). Dredged material will also have to be disposed of in an environmentally acceptable location.

Dock spillage is another possible impact of ocean delivery of storage substances. Spillage from the docks can be minimized by installing the meters, slop tanks, and vents on the land rather than on the dock. The installation of a solid dock surface rather than grating also reduces the possibility of spills (Home Oil Company Limited and Gulf Canada Limited, 1979).

Regardless of the type of substance stored, some sort of pipeline will be required to carry the substance and the brine to and from the storage cavern. One possible impact of pipeline construction is increased soil erosion. Erosion can be minimized by backfilling as soon as possible after the ditch is opened, constructing the pipeline on a shallow slope, and reseeding after installation. Where pipelines cross streams, increased stream flow and erosion may occur. This can be decreased by minimizing cleared width of forest at stream crossings, by carrying out construction during low flow periods and by reseeding after installation of the pipe.

Acid generation is a possibility from some geologic formations in Nova Scotia, particularly in areas underlain by the Halifax and Goldenville formations. Sulphide and pyrite-mineralized zones also occur locally within the Windsor Group evaporite/carbonate sequence which typically host the salt deposits. The potential for acid generation from these deposits

is minimal because of the generally large buffering capacity of these rock types.

Clearing the vegetation from the pipeline area may impact wildlife habitat. Studies should be carried out prior to installation to determine the relative significance of this concern. The pipeline will increase access to the area and therefore may increase human activity and related pressures on the wildlife populations. However, the new edge habitat created will be advantageous for deer. Dust created during construction can be controlled by conventional procedures.

11.3.2 Operation

The area over the pipeline will have to be kept clear of large vegetation. This may be accomplished mechanically or by the controlled application of herbicides with the accompanying impacts of the use of such chemicals.

Pipelines are most commonly damaged by third parties during excavation. The likelihood of a rupture of pipeline in isolated areas is very low. Should a rupture occur, there is a serious possibility of fire, especially with products such as natural gas and liquefied petroleum gases. Security concerns regarding potential vandalism or sabotage should also be addressed in the design phase of the pipeline system.

11.4 Water Supply System

The water supply system includes the pipelines, pumps, and wells which may be required to supply the water to create the storage cavern.

The nature of the impact of the water supply system will depend on the source of water. Withdrawal of significant quantities of water from lakes or rivers may decrease the quantity of water present, particularly during low-flow periods with corresponding effects on the ecosystem of the water body (discussed further in Section 12.0). Water taken from marine sources generally has no significant impact. One impact of taking water from either of these sources is the potential entrainment of aquatic life into the leaching water or onto the screens of the intake pumps. This can be decreased by minimizing the intake velocities or using other specialized avoidance techniques.

11.5 Brine Disposal/Storage System

11.5.1 General

Typically, the brine disposal system will include a surge pond or holding pond located on the storage site, brine disposal pipelines, pumps, and a method of disposing of the brine. This may involve deep injection wells or diffuser ports for ocean disposal. Dilution stations may be used to dilute the brine for disposal in restricted circulation areas such as bogs.

The groundwater environment could be significantly impacted should brine-pond losses occur. The possibility of such losses occurring could be minimized by lining the ponds with low permeable liner and establishing an underdrain system that could collect brine overflows or seepage. Piezometers could be installed around the brine pond to monitor groundwater flow and quality.

Should fuel oil or other liquid hydrocarbons be stored in the cavern, brine may become contaminated with hydrocarbons, resulting in contamination at the brine disposal site. Oils are also used in construction of most caverns as blanket material. To minimize the possibility of hydrocarbon contamination at the disposal site, a continuously operating hydrocarbon detector can be located at the brine pond to ensure that only oil-free brine is sent to the disposal site. The salt tends to inhibit the formation of oil-water emulsions and little of the brine solution is in contact with the oil. Therefore, oil-brine contamination is not expected to be significant. The detection system is designed to direct contaminated brine to an API oil-water separator where the oil can be skimmed off and returned to the caverns. The discharge water is then treated with a mixed media gravity separator to trap the remaining free oil (Home Oil Company Limited and Gulf Canada Limited, 1979).

Proposals for development of salt cavern storage facilities in Nova Scotia completed to date have assumed that the salt brine produced will be disposed of in the ocean (Home Oil Company Limited and Gulf Canada Limited, 1979 and Montreal Engineering Company Limited, 1979). Alternatives to sea disposal of the brine include deep well injection and disposal in an old salt cavern. The latter has been used in Watkins Glen,

New York, by the International Salt Company (Jacoby et al., 1973). Deep well disposal will be discussed in Section 11.5.3. Alternatives to dumping the brine (Blamire 1988) include:

- extraction of salt from the brine for commercial sale,
- sodium hydroxide extraction for possible use in a flue gas desulphurization plant, and
- feedstock for a chlor-alkali or petrochemical production facility, including chlorine production by electrolysis of brine.

Use of the brine for any of these alternative purposes requires that it proves economically feasible on its own merits however, and in many of the U.S. Gulf Coast storage cavern developments the brine is simply discharged to the marine environment.

11.5.2 Ocean Brine Disposal

In this method of disposal, brine is pumped from the cavern into pipelines and then into the ocean through a diffuser tube. A diffuser is a pipe with holes located several metres apart. The diffuser can be placed near the surface of the ocean or on the ocean bottom. The former allows the brine to sink through the ocean water column diluting the effluent as it goes. This technique requires a deep disposal site. At the proposed Home Oil brine disposal site in the Strait of Canso, it was estimated that "disposal of the brine in this manner would result in dilutions in excess of 100" (Home Oil Company Limited and Gulf Canada Limited, 1979).

Placing the diffuser on the ocean bottom is not as effective as the aforementioned, but does not require the ocean location to be as deep. The diffuser is placed pointing upwards.

Both techniques will impact on the ocean environment. The magnitude of change in salt concentration in the ocean will depend on local circulation, relative density of effluent, and the extent of mixing and diffusion in the receiving water.

At Port Richmond on the Strait of Canso, Montreal Engineering (1979) modelled the disposal of 0.05 cubic metres per second of brine (240 parts per thousand - ppt - chloride) from a bottom diffuser. In a worst-

case-situation model, they found that the area within which salinity levels would be more than 5 ppt above ambient levels would be less than 3600 square metres (60 m x 60 m). At the shoreline (1.3 km from the diffuser), salinity increases would be between 0.25 and 0.4 ppt above ambient levels.

Increased salinity causes organisms to undergo physiological stress which includes abnormal behaviour, increased respiratory rates, impaired reproduction, and mortality. Montreal Engineering (1979) hypothesized that there would be an exodus of mobile epifauna (starfish, shrimp, crab) from the immediate area around the diffuser pipe. Less mobile forms such as polychaetes, clams, and amphipods would likely not survive. A short distance away from the diffuser, these animals would probably persist in reduced numbers (Montreal Engineering Company Limited, 1979). Studies by Dow Chemicals (1967) and Mackin (1973) found marked reduction in numbers of organisms within the hyper-saline sphere of influence around brine diffusers. Demersal fish and herring, mackerel and salmon were expected to avoid the diffuser area. Although the chloride plume was expected to deflect fish, they did not anticipate that it would act as a barrier to prevent fish migrations.

Montreal Engineering (1979) expected impact on brine disposal on the inshore vegetation to be minimal. Shallow water marine plants are generally tolerant of variations in salinity and would live outside the area of highest salt concentrations directly next to the diffuser. Outside the 60 metre sphere of influence of the diffuser, the normal bottom plant population was expected to persist. No anoxic layer was expected to develop due to dispersion of the plume by natural currents.

A number of trace metals found in salt deposits have been shown to be toxic to marine organisms at low concentrations if present in a bio-available form (Home Oil Company Limited and Gulf Canada Limited, 1970). Montreal Engineering (1979) found that after dissolution of a composite salt sample in tap water, the metals - iron, lead, copper, and zinc - increased in concentration. This may suggest that some small pockets of these metals exist in the formation salt at Port Richmond. It was also found that lead, zinc and mercury increased in concentration in the receiving seawater after the addition of the prepared brine. The lead increase of less than 0.02 mg/l was not considered to be significant. Zinc

and mercury concentrations increased three to four-fold. However, both concentrations were within the natural range of concentrations found in the area and were not considered to be significant. It should also be noted that analytical methods for trace metals in sodium chloride brines are often difficult because of the overwhelming interference of the large cations such as Na and Ca.

Brine was also exposed to sediment. The mercury concentration in the sediment increased three-fold, slightly greater than the two-fold variation found naturally. This might reflect some mercury migration from the brine into the sediment (Montreal Engineering Company Limited, 1979). Other metal concentrations in the sediment did not increase when exposed to the brine.

Clay fines associated with salt deposits may be discharged at the brine outfall and may settle on the relatively quiescent ocean bottom. There may also be a concern with the trace metals which can absorb on the clay particles and their effects on biota. The salt from the Port Richmond site was found to contain approximately 635 mg/kg insolubles. Montreal Engineering found that 90 percent of the solids settled within the first hour. Accordingly, they concluded that the majority of the insolubles would not leave the salt caverns and there would be minimal effect on ocean organisms.

At the Home Oil site, an addition of a significant volume of brine water (2 cubic metres/sec) was planned to be added to the strait. The effluent will entrain brackish surface water, take it to the bottom and flow out over the estuary sill (i.e. a reverse estuary) (Home Oil Company Limited and Gulf Canada Limited, 1979).

In instances where the brine must be disposed of in bodies of water with restricted circulation (bogs, estuaries), the brine may have to be diluted prior to discharge, in order to minimize the environmental impact.

11.5.3 Deep Well Brine Injection

11.5.3.1 Introduction

Deep-well injection of liquid wastes has been practiced in the US for more than 50 years. In 1986, there were slightly more than 327,000

injection wells in the US. More than half of these wells are related to the petroleum industry and are used for disposal of oil field brine waters (Mankin and Moffett, 1987).

There are 31 registered disposal wells in Canada: 16 in Ontario, 10 in Alberta, 4 in Saskatchewan, and 1 in Manitoba. The wells in Ontario are generally less than 300 metres deep while those in western Canada range from 420 to 1,550 metres deep (Van Everdingen and Freeze, 1971). According to Section 35 of the Well Drilling Act (1987), a well is not to be used for waste disposal in Nova Scotia without the approval of the Minister of the Environment.

When injected in the ground, the volume of water is compressed by the higher confining pressures, undissolved gases in pore spaces are compressed, rocks are deformed and uplifted to some extent, and existing fluids are displaced (Tofflemire and Brezner, 1971).

The major advantages of waste brine injection are that the waste is entirely removed from surface waters, it is more economical than treatment, and little land is used. It has been used successfully with over 40,000 salt brine wells in the US (Tofflemire and Brezner, 1971).

11.5.3.2 Possible Environmental Impacts

The practice of deep-well injection of salt wastewater may have the following effects:

- salt contamination of freshwater aquifers,
- accelerated discharge of saline water in discharge areas,
- hydraulic fracturing of the disposal formation and the confining beds, and
- increased earthquake activity.

Pollution may occur through injection well failure, seepage through geologic faults, seepage through abandoned wells, and hydraulic fracturing of the confining beds. The long-term effects of deep well injection are unknown. Pollution of the overlying aquifers is difficult to detect and essentially impossible to correct once it has occurred. The risk of such pollution can be minimized by the mitigative measures described in the following section.

11.5.3.3 Mitigative Measures

To minimize the possibility of the occurrences of environmental impacts, the site for deep-well injection must be properly selected. There is no practical level of engineering that can convert a poor site into a favourable site for deep-well injection. Therefore, sites must be selected based on geological conditions, not proximity to the waste source (Goolsby, 1971).

The ideal geology is that with low permeable rocks (shale, clay, salt) above and below a more permeable disposal zone. Sand, sandstone, and limestone are the best materials for the waste injection. Faulted areas and areas subject to seismic activity should be avoided (Tofflemire and Brezner, 1971).

Van Everdingen and Freeze (1971) have listed the following criteria for acceptable areas for deep-well injection:

- . extensive thick sedimentary sequences,
- . thick disposal formation, with adequate porosity and permeability and large areal extent,
- . homogeneous disposal formation,
- . overlying and underlying strata of sufficient thickness and low permeability,
- . injection beds adequately separated from potable water zones,
- . free from major faulting,
- . waste injection not endangering present or future use of mineral resources,
- . formation water has no apparent economic value,
- . no unplugged or improperly abandoned wells capable of penetrating the disposal formation,
- . formation fluid pressure low (therefore can have higher injection pressure) which minimizes the chance of backflow in the case of pump or well failures,
- . vertical, downward hydraulic gradients,
- . slow lateral groundwater movement to prevent rapid movement to a natural discharge area,

- . low seismic risk, and
- . low hydrodynamic gradients prevailing over a large part of the region.

The injection well must be designed so that it protects against the contamination of freshwater zones through well-failure or corrosion of casing by injection fluids or formation fluids (Tofflemire and Brezner, 1971). The well must be cased/cemented through all potable aquifers and unconsolidated sediments. This can be verified by logging and monitoring temperature and cement bond properties and by pressure-testing. The corrosiveness of brines should be taken into account in the selection of casing and tubing and cement additives. Water injection tests must be conducted to determine the maximum input pressure which will not cause hydraulic fracturing and damage to confining beds. There must be sufficient surface storage for waste produced during shut-down periods (Van Everdingen and Freeze, 1971).

A monitoring program must be in place to detect abnormal operating conditions or well failure. Injection pressure and flow should be continuously monitored and checked for unusual variations. High and low pressure alarms should be installed. The annular space between casing and injection tubing must be closed off and filled with non-corrosive liquid to monitor for leads in either the casing or the injection tubing (Van Everdingen and Freeze, 1971). The injected volume and the waste composition should also be monitored.

Observation wells must be installed in the formation to allow interpretation of pump and injection test results and monitor formation pressures during waste injection. Freshwater observation wells must be installed and periodically monitored.

There have been relatively few instances of groundwater pollution resulting from deep-well injection over the 50 years or more, they have been in use. The following are a few instances where pollution has resulted from deep-well injection.

At a US steel site in Jackson County, Ohio, pumping 1.43 million cubic metres of liquid waste into the bedrock has fractured the overlying formation and the waste has most likely migrated upward (Ahmad, 1979).

At the Hammermill Paper Co., in Erie, Pennsylvania, 700 metre well injection tubing failed in April 1968. Wastewater was blown high in the air and flowed into Lake Erie for several days. The waste water had corroded one of the pipe joints and allowed water to escape up the annulus of the well (Tofflemire and Brezner, 1971).

Fluid was injected through the 3,671 metre Rocky Mountain Arsenal disposal well into fractured Precambrian gneiss at 8 litres/second for 18 months in 1962 to 1963. This apparently caused an increase in the number of small earthquakes in the Denver area (Tofflemire and Brezner, 1971).

Brine disposal into the Permian Basin in Texas and Oklahoma has apparently resulted in increased salt water seepage into area streams (Piper, 1970).

Injection of wastes into relatively shallow wells in Ontario has apparently caused the wastes to discharge into the St. Clair River and seep to the ground surface in Port Huron, Michigan (Van Everdingen and Freeze, 1971).

12.0 SOURCE OF BRINE LEACH WATER

The rate at which water must be supplied for brine leaching is dependant on economic and scheduling requirements. Commercial brining rates for salt production typically range from 50 to 100 cubic metres per hour. Economic rates for a single cavern being leached for storage space are 500 to 1000 cubic metres per hour. Large operations might require as much as 1500 cubic metres per hour (Dreyer, 1982). The amount of water required will depend, in part, on the salinity of water. Should the source of water be fresh, less water would be necessary. Seawater already contains salt and, therefore, is slightly less capable of dissolution of the salt in the cavity.

At the locations near Boularderie, Kingsville, McIntyre Lake, and Port Richmond, seawater is the most likely water source. Home Oil and Gulf Canada Limited (1979) proposed to build a 16 kilometre long pipeline from the Strait of Canso to the McIntyre Lake site and then another 16 kilometre long pipeline from the McIntyre Lake site to the Kingsville site. Water for Boularderie development can be obtained from either Bras d'Or or St. Andrews channels which are saltwater bodies.

The area with greatest potential difficulty in locating a source of water is the Shubenacadie-Stewiacke area. The two major rivers in this area are the Shubenacadie and Stewiacke Rivers. The rivers have the following flow-characteristics (Environment Canada, 1987):

Shubenacadie River at Enfield:

Minimum Daily Flow:	248 cubic metres/hour (84/11/11)
Mean Monthly Flow:	4570 cubic metres/hour
Total Annual Discharge:	407,000 cubic decametres
11 Years Record	

Stewiacke River near Upper Stewiacke:

Minimum Daily Flow:	511 cubic metres/hour (81/09/05)
Mean Monthly Flow:	3920 cubic metres/hour
Total Annual Discharge:	320,000 cubic decametres
11 years record	

From the above information, it is evident that at low-flow periods there is insufficient water flowing in the river to provide the 500 to 1000 cubic metres/hour of water required for even a small salt-brining project. The use of water from these rivers without impact on fish populations and downstream users will require controlled withdrawals at specific times during the year. Substantial tidal ranges exist in both of these rivers however, and increased volumes of water may be obtainable within the tidal zone. Brine disposal within this zone may also be a more feasible option.

PART E

ECONOMIC CONSIDERATIONS

PART E: ECONOMIC CONSIDERATIONS

13.0 CRUDE OIL STORAGE - ECONOMICS

13.1 Background

Because of the low containment pressure requirements for crude oil storage and because of a generally low requirement for crude oil surge storage (due in part to its high energy density), commercial storage of crude oil in subsurface caverns is not frequently done. In some European countries, crude oil suppliers are required by law to maintain a reserve supply, and in these cases, salt caverns are often used. This, of course, is not a pure commercial application.

In the United States, 86 million cubic metres (540 million barrels) of crude oil are presently stored in salt caverns in the Strategic Petroleum Reserve (SPR) located in Texas and Louisiana. This reserve is totally financed by the United States Government and is intended to limit US vulnerability to oil supply disruption and to meet US obligations under the International Energy Program. Present plans and funding are to provide 120 million cubic metres (750 million barrels) of storage capacity by late 1991, all on the US Gulf Coast. The original intent of the Energy Policy and Conservation Act (1975) was to provide 160 million cubic metres (one billion barrels) of crude oil storage. There is now some discussion in the US Congress on providing funding for the remaining 40 million cubic metres (250 million barrels). The US east coast receives virtually all of its crude oil by ship and is not connected to the present SPR facilities by pipeline. In the event of a disruption, supply to the east coast would have to be by tanker from the Gulf of Mexico. This puts Nova Scotia, with the only other suitable salt deposits, in a very competitive position, particularly with respect to the northeastern (New England states). Eastern Canada, of course, is also heavily dependent on imported oil. The St. Lawrence Seaway is also convenient to the Canso deep-water port.

Earlier studies (ref. Home Oil, Domtar, etc.) have shown that the Strait of Canso area (Port Richmond, McIntyre Lake, and Kingsville Deposits) offers a near perfect location for a regional reserve serving New England and the Canadian east coast. Sections 9.4, 9.5, and 9.8 of this

report discuss the geology and salt characteristics of these sites in detail. Some of the apparent advantages of the Canso area sites are:

- . proximity to an ice-free, deep-water port;
- . close to US and Canadian demand;
- . ample leaching water supplies - either surface or seawater;
- . sufficient volume of salt; and
- . ease of brine disposal to the ocean.

Most of these topics have been addressed in length in earlier studies (ref. Domtar, Home Oil, etc.). Of particular interest for the development of a petroleum reserve is the space available. A problem with the existing US reserve has been the increased staffing and maintenance costs required by creating several small sites serving the same demand. This is not a problem with the Port Richmond Deposit - it is estimated that it can be leached to hold a maximum volume of approximately 300 million cubic metres (2 billion barrels). It is estimated that the adjacent McIntyre Lake Deposit is even larger (although less well characterized). Thus, size is not an issue. The fact that some of the Port Richmond Deposit is under shallow water does not present a problem from a leaching or storage standpoint. Many salt caverns have been developed beneath the shallow waters of the Gulf of Mexico and the technology is well developed.

The Shubenacadie-Stewiacke Deposit in the Hants-Colchester area is not as strategically well located as the Canso area relative to trans-shipment. However, from a space-availability point of view, this is an equally interesting site. It is estimated that the maximum storage capability of this site is some 300 million cubic metres (2 billion barrels). From a geological point of view, this is a fairly well-defined, less complex deposit. However, the position of the deposit in the interior of the province (60 km from Halifax) may preclude crude oil storage at this site at present.

Clearly, the motivation to build a crude oil reserve has to come from governments concerned with national economic well-being. One of the primary factors for the US in not proceeding with a Nova Scotia reserve in

the late 1970's was the desire for a central storage location which could serve the interior by pipeline. Since that time, two of the three major commercial pipelines intended for that task have been converted to natural gas transport (Texoma and Seaway), leaving much of the distribution task to tankers. This argues against further centralization of the SPR and mitigates in favour of a reserve serving the US east coast. Because so much refined product is shipped through the east coast (US and Canada), it may be desirable as well to consider storage of these products in a strategic reserve. Heating and fuel oil especially, can be stored in salt without deterioration.

Other potential users of a storage reserve are the OPEC Nations. Saudi Arabia has recently chartered five VLCC's (total of 1.6 million cubic metres - 10 million barrels) for the purpose of storing excess production at sea (Wall Street Journal - 1/27/88). This is very expensive storage. Charter costs are on the order of \$21 Cdn. per cubic metre (\$2.50 US per barrel) per year. In addition, Saudi Arabia has its own on-shore surface storage capacity of 8.5 million cubic metres (53 million barrels). This storage is vulnerable to the mid-east turmoil and the Saudis have, for several years, been considering subsurface storage; at first in their own territory and more recently have been making inquiries in the US.

Storage in the US or Canada would have several advantages for the Saudis or other mid-east nations. The oil would be safe, both politically and strategically; it would be close to the likely market; and the cost of the stored oil would be simply their production and transport cost, which is far below the current crude oil market price (Saudi production costs have recently been estimated at \$4.20 Cdn. per cubic metre - \$0.50 US per barrel). In the event of war or other national emergency, the stored oil would provide the affected nation with an uninterrupted source of income, (in effect an "oil bank").

13.2 Petroleum Reserve Cost of Construction

The Canso sites appear ideal for minimizing the cost of producing storage space. Ease of obtaining leaching water and disposing of the brine is provided by the near-shore location. Land costs are comparatively low and the proximity of the deep-water port means low pipeline costs.

The Shubenacadie-Stewiacke deposit does not have the location advantages of the Canso sites, but has a less complicated geology. Technical feasibility and economic analysis will have to be performed to properly assess the best location.

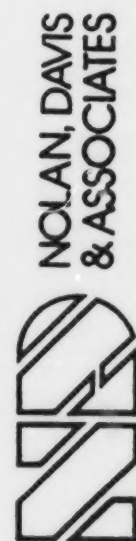
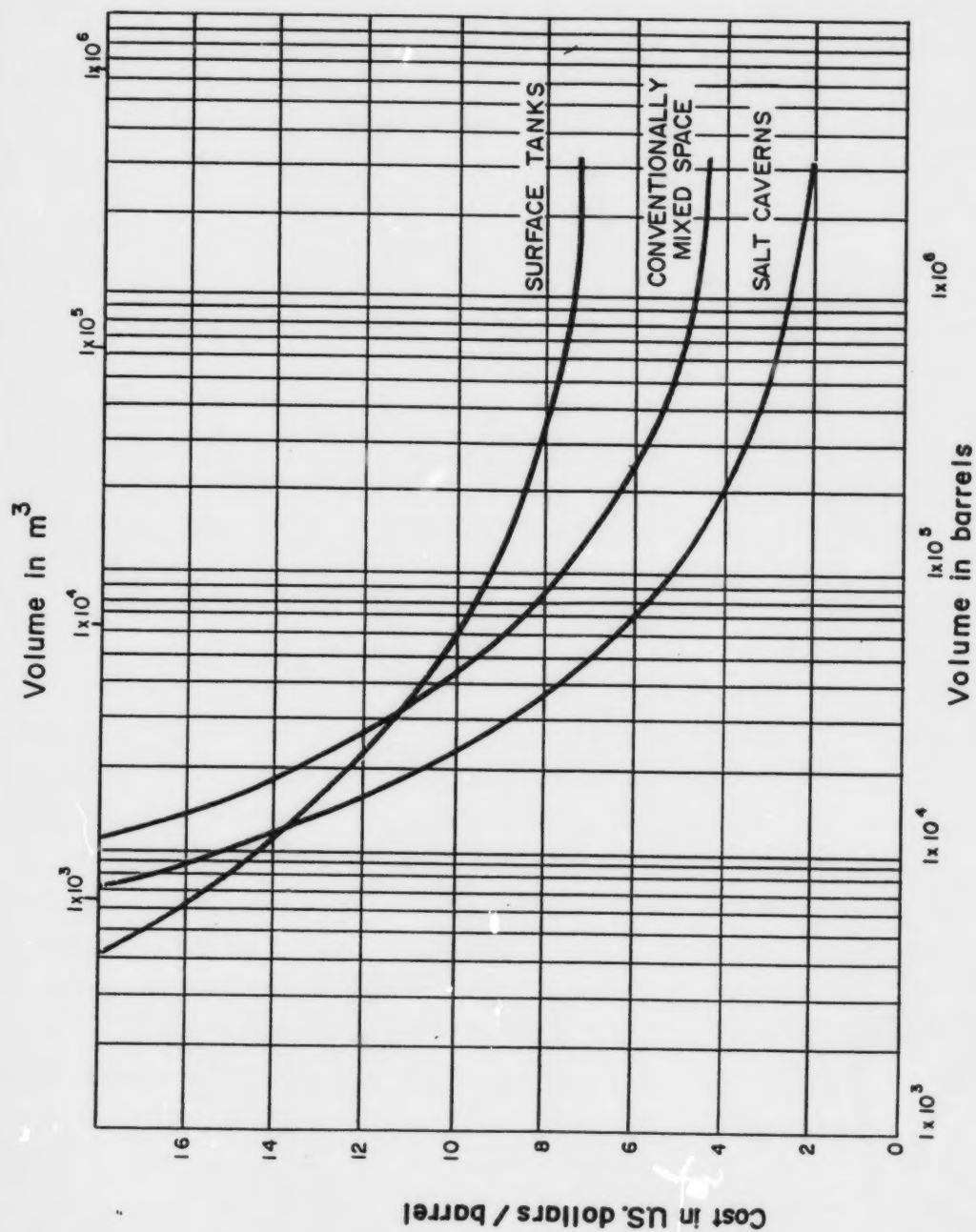
Figure 13-1 shows a comparison of construction costs for crude oil storage for various types. For large volume, salt caverns are very competitive and it is likely that the Nova Scotian deposits would fall near the low end of this range, approximately \$16.80 Cdn. per cubic metre (\$2 US per barrel).

13.3 Economic Conclusions

It appears that in the current economic and energy supply climate, large-scale storage of crude oil and storage of refined product in Nova Scotia is economically feasible. Potential users are the US, Canada, and potentially any mid-east OPEC nations. It is considered that the Canso area is ideal from almost every aspect. The Shubenacadie-Stewiacke deposit also appears to be a good candidate. A joint development, perhaps within the framework of the Free Trade Agreement, would be advantageous to all parties.

14.0 LIQUEFIED PETROLEUM GAS (LPG) - ECONOMICS

Nova Scotia's present use of LPG is small (1985 - 30,000 m³ per year). This is roughly 100 m³ per day per 1000 people. In the United States, per capita use of propane is greater (a total of 70,000 m³/day or roughly 300 m³/day per thousand). However, in areas of the United States where piped natural gas is not available, LPG competes strongly with fuel oil and electricity. Although it is more expensive, it burns much cleaner than fuel oil and is normally cheaper than electricity. Table 14-1, below, compares the average costs of other energy sources to that of propane.



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FIGURE 13-1

COST COMPARISON FOR DIFFERENT STORAGE METHODS

CRUDE OIL

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MAR. 1968

TABLE 14-1

Average Residential Fuel Costs

	US Experience (1980)		NS Experience (1987)		
	Cost Per Million kiloJoules \$US	Ratio to Propane Cost \$Cdn.	Cost Per Million kilo- Joules (\$Cdn.)	Ratio to Propane Cost	
Propane	4.52	6.03	1.0	11.69	1.0
Natural Gas	2.59	3.70	0.6	NA	-
No. 2 Fuel Oil	3.76	5.01	0.7	9.32	0.8
Electricity	13.29	17.72	2.6	20.90	1.8

Source: Southam Energy Group, 1980; sales of Refined Petroleum Products, Statistics Canada Catalogue 45-004, 1987.

For each area, the first column shows the cost of the various fuels per million kiloJoules and the second column shows the ratio of this cost to that of locally delivered propane. This price structure allows propane to compete quite well in rural areas. If the ratio is improved in Nova Scotia in favour of LPG by the availability of cheap, indigenous product from one of the proposed offshore energy developments, use could far exceed the United States experience on a per capita basis. Climate and the local, relatively high price of fuel oil, would also push in this direction. Because of the pressure requirements for LPG storage (propane vapour pressure equals 1.4 MPa at 37°C), salt cavern storage of LPG is competitive with surface tank storage down to very small sizes.

Typical LPG storage caverns are in the 15,000 to 30,000 m³ range. Many are much larger. Costs are from three to seven times cheaper than surface tanks depending on site specific factors. Since present Nova Scotia consumption is about 30,000 m³ per year, use would have to increase greatly to justify cavern storage. Of course, future use as commercial feedstock for a petrochemical industry is also possible. If there is a

potential for use to increase sufficiently to warrant cavern storage, many of the Nova Scotia salt deposits are physically adequate. As discussed previously, salt deposit depth and site requirements are minimal for LPG storage. Primary economic concerns would be: location near demand, residential or commercial; location near supply, preferably by ship, although ship to rail is also feasible; and finally, a need for surge storage. The latter arises when the supply is by ship, as from the Venture Field, or when there is a strong seasonal change in demand, as would also be true of Nova Scotia heating requirements.

In summary, potential for LPG cavern storage exists, providing Nova Scotia production becomes available. In addition to cost advantages, all the other subsurface advantages apply to propane storage: safety to people, reduced land use, improved environmental protection, increased protection from natural disasters, and finally, minimum impact on the scenic environment. However, the primary factors for evaluation of LPG storage economics - production cost and potential markets will have to await developments on the Venture Gas project and/or other East Coast energy developments. For the present, LPG storage is not feasible.

15.0 NATURAL GAS STORAGE - ECONOMICS

15.1 Background

The viability of the Venture project has been tied to, among other factors, the guaranteed export to and purchase by New England states of a substantial portion of the gas. As well, with the expected adoption of the Free Trade Agreement, trade with Nova Scotia's most accessible market, the East Coast of the United States, is likely to grow dramatically. This enhanced trade will potentially encourage the development of a local industrial base that has access to a clean, economical fuel - natural gas from the Venture field.

Both of these uses for the Venture gas - local industrial use (and perhaps domestic use) plus export requirements - will be subject to cycles of varying demand dictated by seasonal energy use (heating/air conditioning, etc.) requirements. Since surge storage to accommodate seasonal demand cycles is a normal component of a natural gas transmission

system, it is logical to consider Nova Scotia salt deposits to provide this function.

The combination of recently depressed hydrocarbon prices and high start-up capital cost estimates have delayed the proposed pipeline from the Venture Field until higher stabilized gas prices are realized. In addition, 31 United States pipeline groups are now competing to extend existing gas services into New England (Oil and Gas Journal, March 28, 1988). Plans are also under way to restart LNG shipments from Algeria to Boston (Chemical Week, July 22, 1987). Since the maritime market will not yet by itself support a major natural gas project, it is with these other potential New England projects that Nova Scotia gas must compete in price.

With this in mind, it was decided to look at other options for gas transmission that would allow early use of both the gas and the salt and also be competitive in the New England market.

15.2 Alternate Modes of Natural Gas Transport

The proposed pipeline from the Venture Field, extending through Nova Scotia to the United States border and from there to Massachusetts, has a presently estimated cost of approximately \$5.80 billion Canadian (\$4.35 billion US - Oil & Gas Journal, October 1987). This includes off-shore production development costs as well as the pipeline. This large initial investment not only increases the risk of the project, but results in a cost of over \$0.14 Cdn. per cubic metre (\$3 US per MCF) just to deliver the gas. Royalties, taxes, profit, and payment for the in situ gas would be extra. Natural gas provided to New England utilities by the Algonquin and Tenneco gas lines currently costs \$0.14 Cdn. per cubic metre (around \$3 US per MCF - Source: American Gas Association). This, however, is a temporary situation dictated by earlier natural gas contracts. A more realistic price based on the expected developments discussed earlier is between \$0.14 to \$0.28 Cdn. per cubic metre (\$3 to \$6 US per MCF). This is based on present United States feedstock prices plus estimated transport costs. Natural gas prices are expected to rise in the long-term, so the overall situation could improve. With this background, three optional modes of transport were considered:

- 1) Tanker transport of liquefied natural gas (LNG);
- 2) Conversion of natural gas to methanol and shipment by conventional tankers; and
- 3) Barge transport of compressed natural gas (CNG).

Option 1), tanker transport, in general has the same problem as the proposed pipeline - a very high start-up cost, particularly for an offshore plant. In addition, calculations show that for the relatively short shipping distance required here, it is not competitive with Option 3), compressed natural gas. In regard to the New England market, there already exists a LNG system - idle liquefaction capacity in Algeria and idled LNG tankers in the United States. These can be operated at prices to cover the variable cost, capital costs having been to a great part written off. Thus, this source represents part of the competition, as mentioned in Section 15.1.

Option 2), conversion to methanol, is a simple chemical process which can be carried out at the pipeline landfall or offshore. Methanol is primarily used as a feedstock for chemicals and also as an additive to gasoline. The cost for this conversion and transportation would be significantly above that for either LNG or CNG on a per Joule basis, although it sells for considerably more. Also, the demand is limited and the product would not alleviate the primary need for cheap energy in Nova Scotia and New England.

Option 3), transport by barge, appears to be the optimum solution, with a production and transport cost of approximately \$0.09 Cdn. (\$0.07 US) per cubic metre. This excludes the in situ gas costs. This appears very competitive with the New England market. The concept and details of the cost analysis are discussed in Appendix D.

16.0 COMPRESSED AIR ENERGY STORAGE - ECONOMICS

16.1 Background

Compressed Air Energy Storage (CAES) is a technology for storing excess electrical energy in the form of compressed air in underground

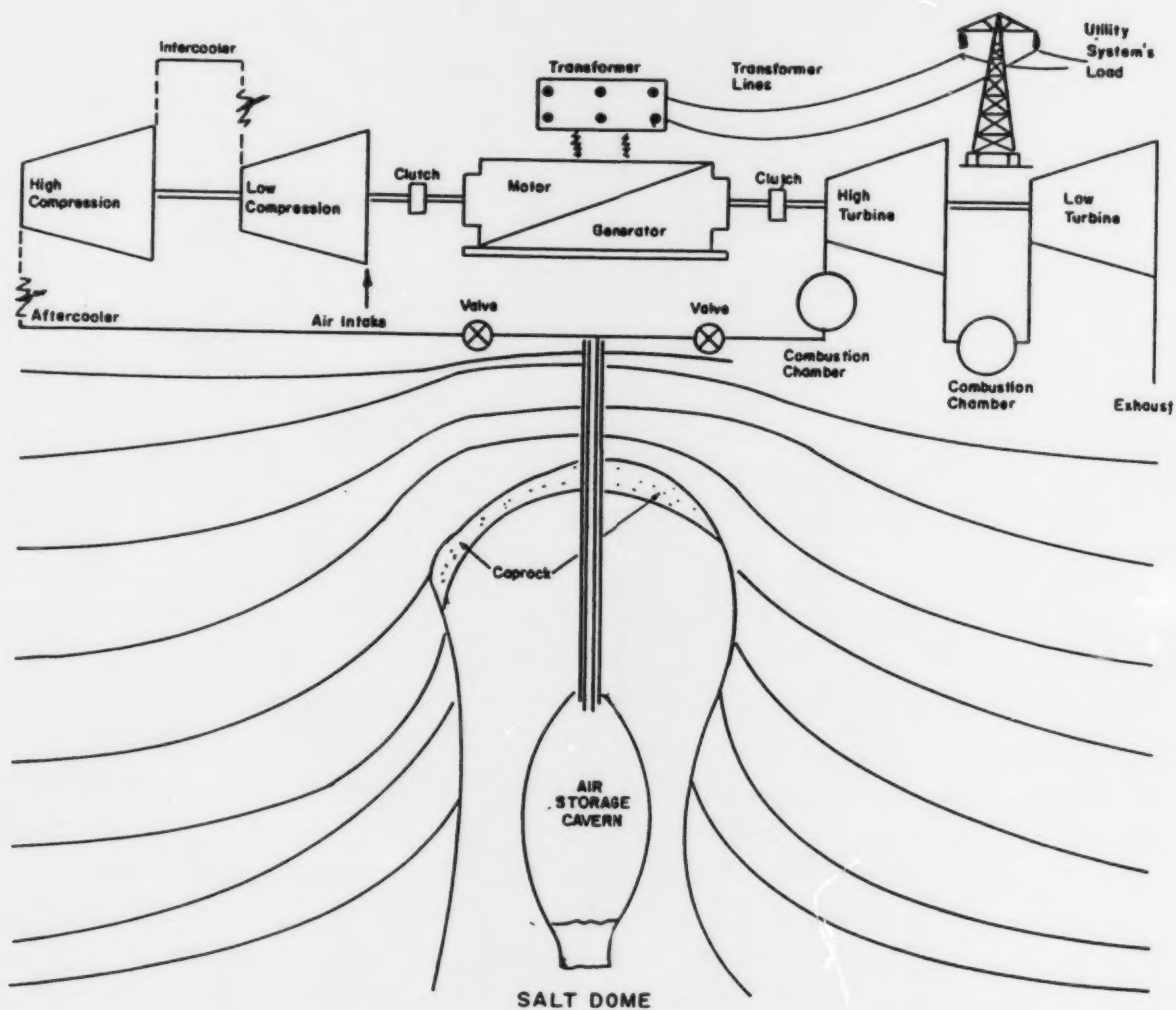
reservoirs (Figure 16-1). The air is later released, mixed with fuel, ignited and expanded through modified combustion turbines to generate peak-load electricity. By compressing the air in advance using excess electricity, the energy of the hydrocarbon fuel consumed in the combustion turbine of a CAES facility is devoted almost entirely to generating electricity. In contrast, a conventional gas turbine must drive its own compressor stage, which absorbs about 60 percent of the fuel's energy content. Therefore, a CAES power plant consumes substantially less hydrocarbon fuel to produce a given amount of power when compared to a conventional combustion turbine peaking plant. Advanced CAES concepts may eliminate the need for petroleum fuel altogether by storing and recovering the heat of compression.

The energy source for compression of the air may be one of:

- hydrocarbon fuel
- tidal power
- hydro-electricity
- solar power
- wind power

Only the first two sources are considered economically feasible on a large scale.

Results of preliminary design studies co-sponsored by the US Department of Energy (DOE) and the Electric Power Research Institute (EPRI) of Palo Alto, California, indicate that CAES is a technically feasible and economically competitive form of generating peaking power. The DOE sponsored and funded various research and development studies for the CAES program. The studies involved investigation/feasibility assessment of compressed air energy storage in three major types of geologic air storage reservoirs: solution mined salt caverns, excavated hard rock caverns, and porous media or aquifer structure reservoirs. Management of the program was provided by the Pacific Northwest Laboratory (PNL), operated for DOE by Battelle Memorial Institute. The EPRI also sponsored preliminary design studies for the development of the CAES program. Apart from the DOE/EPRI sponsored programs, independent studies have also been carried out by other organizations.



**NOLAN, DAVIS
& ASSOCIATES**

**FIGURE 16-1
SCHEMATIC OF A COMPRESSED
AIR STORAGE FACILITY**

H87607

March 1988

16.2 Potential Sources of Markets

16.2.1 Nova Scotia (Domestic Market)

The power supply picture in Nova Scotia shows a heavy dependence on imported oil. Provincial energy plans (NSDME, 1986) have indicated the need to substitute for oil in any possible way and to develop indigenous resources (e.g. Pt. Tupper plant conversion to coal). Present commitment by Nova Scotia Power is aimed at developing new coal fired power plants, since the province has a large coal mining industry.

With ample power generation and the possibility of securing plentiful and economic natural gas supplies, it seems that CAES is not very attractive at the present. If an offshore gas supply doesn't materialize and/or if natural gas prices rise, then CAES may become more attractive. The benefits to be derived from CAES are as much operational as economic.

16.2.2 Nova Scotia (Export Market)

Boston Edison Company and Nova Scotia Power Corporation are conducting a feasibility study to construct a 1200 MW coal fired power plant near Halifax. This plant is to be dedicated to power export to the New England grid. Power transmission is planned to be via submarine cable from Yarmouth (NS) to Plymouth (Maine). Due to its characteristics, this project does not lend itself to include a CAES plant.

16.2.3 Tidal Power Generation

CAES is highly compatible with tidal power utilization due to the cyclic nature of power generation. Although large-scale development of Fundy Tidal Power is not probable in the near future, it is possible that the applicable technologies may improve to the point where such a project is technically and economically feasible. Figure 16-2 illustrates the proximity of the two most feasible tidal power sites to the existing power grid.

16.3 Cost Data for CAES Plants

Figure 16-3 provides an illustration of the typical cost data generated for a proposed CAES plant.

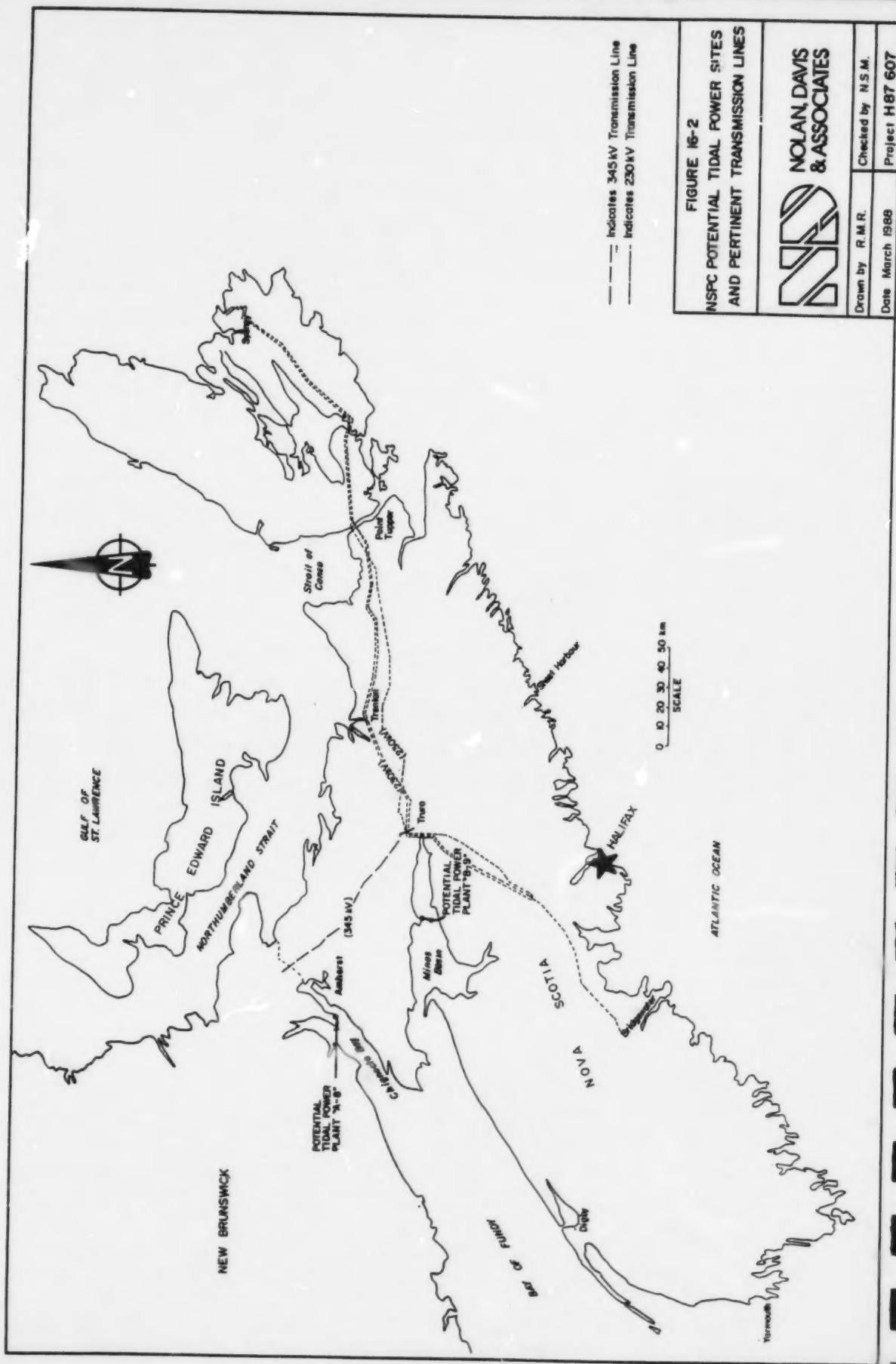


FIGURE 16-2
NSPC POTENTIAL TIDAL POWER SITES
AND PERTINENT TRANSMISSION LINES



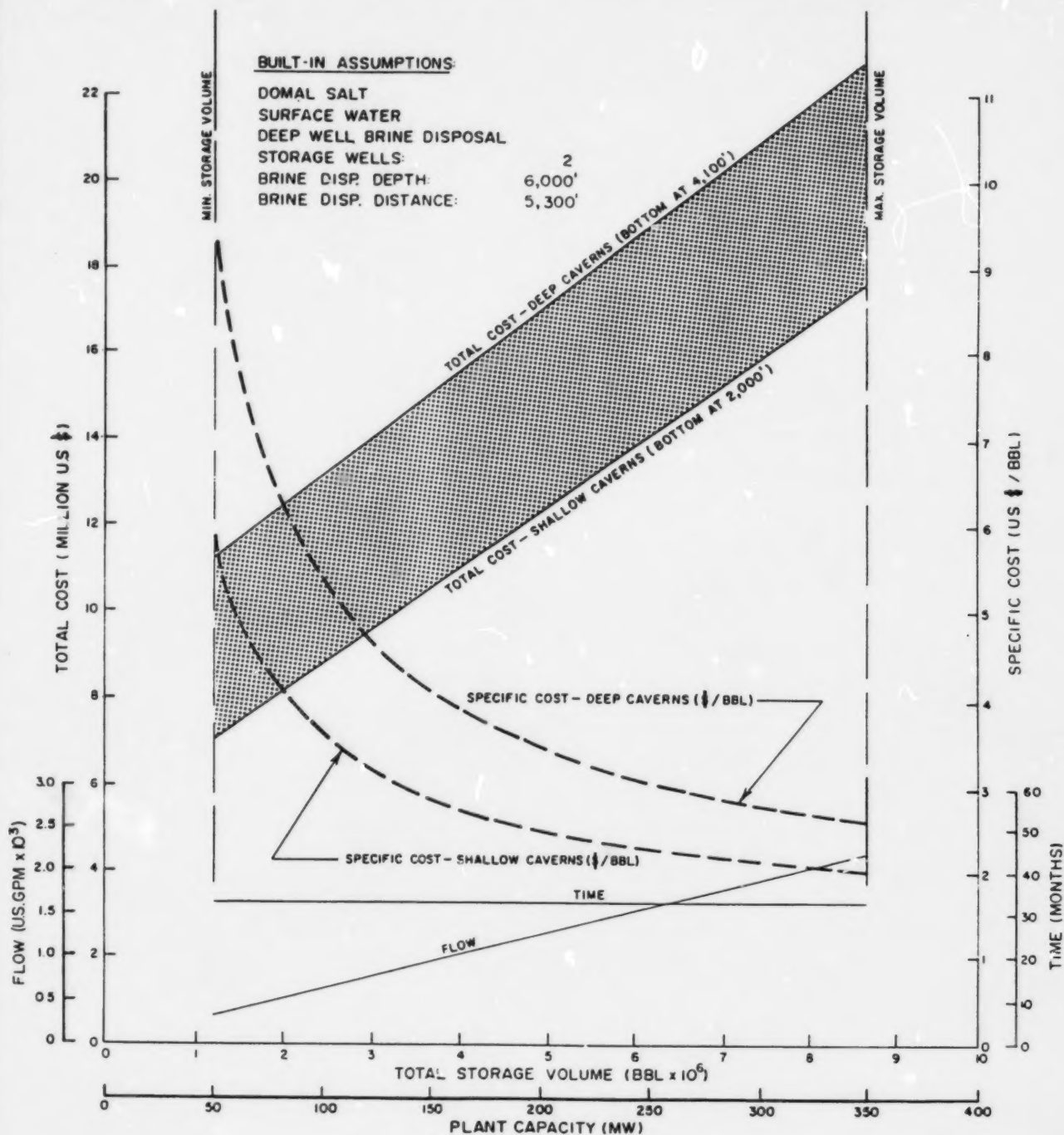
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Drawn by R. M. R.

Checked by N.S.M.

Date March 1988

Project H87 607



PB-KBB Inc.
Subsurface Systems & Technology



**NOLAN, DAVIS
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FIGURE 16-3

LOTS OF REVISED EMPIRICAL COST EQUATION
FOR THE CREATION OF VOLUME
IN SALT DOMES
FOR CAES INSTALLATIONS
(ACCURACY: $\pm 30\%$)

H87607

MAR. 1988



PART F

SITE SELECTION, CONCLUSIONS, AND RECOMMENDATIONS

PART F: SITE SELECTION, CONCLUSIONS, AND RECOMMENDATIONS

17.0 MOST SUITABLE SITES

17.1 Selection Criteria

The following factors have been used in selecting the most promising sites for salt cavern development in Nova Scotia:

- . Sufficient thickness and extent of salt section;
- . Salt relatively free of impurities;
- . Sufficient thickness and type of cap rock;
- . Water available for brining;
- . Disposal site for waste brine; and
- . Proximity to supply and markets.

17.2 Recommended Sites

The following seven sites show the most promise of the 27 examined (see Figure 17-1):

Port Richmond
Shubenacadie-Stewiacke
McIntyre Lake
Kingsville
Nappan
Beaver Brook
Boularderie

Table 17-1 summarizes the appropriate data used in the site selection and the substances considered suitable for storage at each site. Many of the sites lack sufficient information for complete evaluation. In addition, not all of the sites are suitable for storage of all products of interest.

18.0 OVERVIEW OF SITES INVESTIGATED

Of the 27 sites studied, six sites (5 in the Hants-Colchester area and 1 in the Cumberland area - see Table 6-2) were eliminated due to insufficient salt thickness based upon available data. A further six sites (1 in the Hants-Colchester area, 2 in the Cumberland area, 2 in the Canso-Bras d'Or area, and 1 in the Sydney area) were eliminated from further

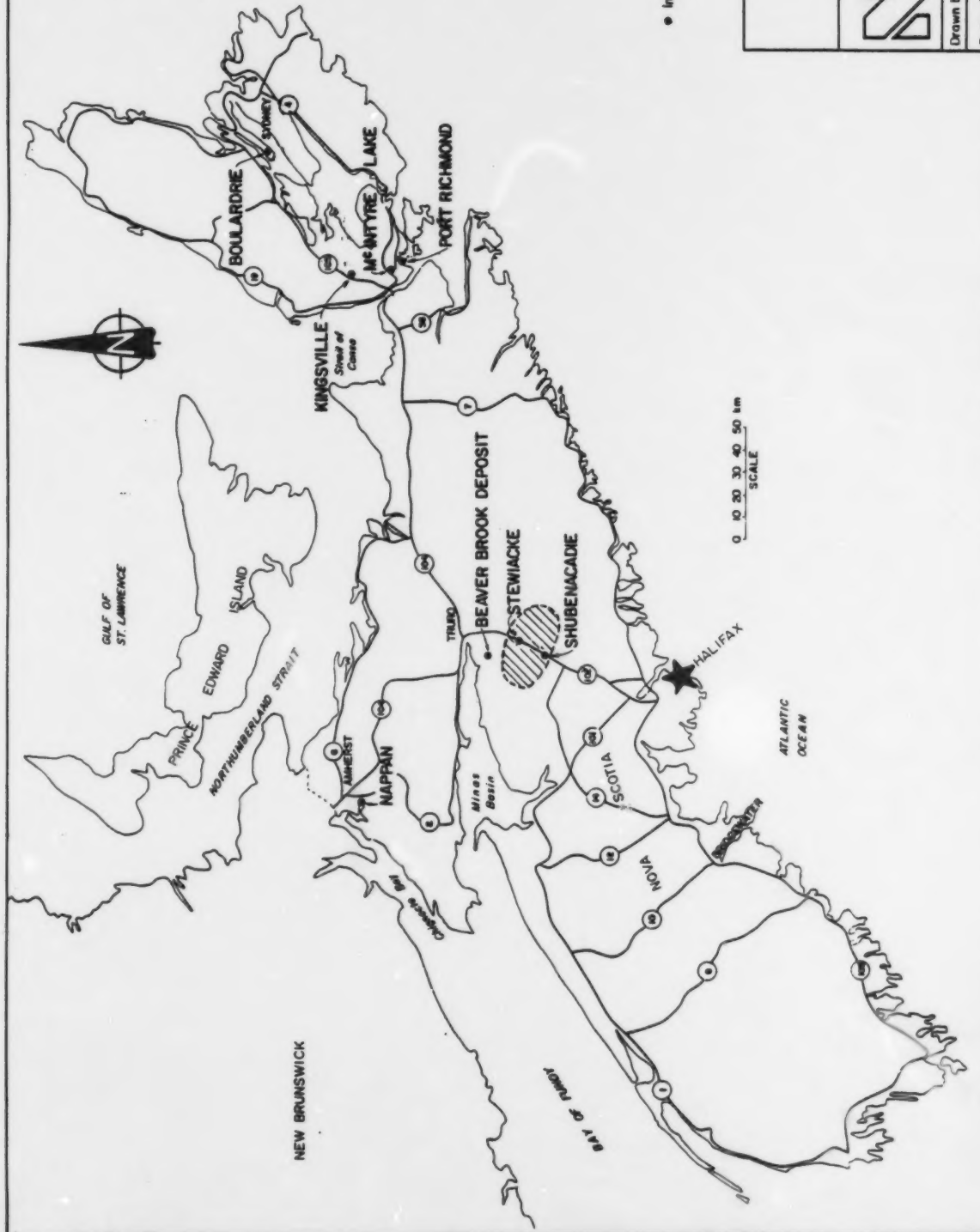


FIGURE 17-1
SELECTED SALT CAVERN
SITE LOCATIONS



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TABLE 17-1

SITE SELECTION DATA SUMMARY

SITES

	Port Richmond	McIntyre Lake	Kingsville	Beaver Brook	Nappen	Shubenacadie -Stewiacke	Boulevardrie
Extent & Thickness	4 km diameter 255 - 1050 m	7 x 10 km 574 m	1 x 10 km 540 m	1 x 5 km 300 - 450 m	4 km diameter 1,300 m	40 x 15 km 300 m	? 335 m
Salt Purity	85%	85%	90%	90%	97%	87%	90 - 95%
Cap Rock	250 - 550 m Shale Quartzite Conglomerate Anhydrite Limestone	255 m Siltstone Gypsum Shale Sandstone Limestone Anhydrite	400 m Siltstone Gypsum Sandstone Conglomerate Mudstone Shale Halite Limestone Dolostone	360 m Shale Siltstone Dolostone Anhydrite Limestone	310 m Shale Gypsum Sandstone Limestone Anhydrite	400 - 500 m Siltstone Gypsum Sandstone Conglomerate Limestone Anhydrite	495 m Sandstone Siltstone Mudstone Limestone Dolostone Anhydrite Gypsum
Water Source	Straight of Canso	Straight of Canso	Straight of Canso	Shubenacadie River	Nappen River	Shubenacadie/ Stewiacke River	Bras d'Or Lake
Brine Disposal	Straight of Canso	Straight of Canso	Straight of Canso	Shubenacadie River	Nappen River	Deep-Well Injection	Bras d'Or Lake
Potential Market	International	International	International	New England	New England	New England, Halifax	Sydney
Suitable Substances	Crude Oil, LPG, Natural Gas	Crude Oil, LPG	Crude Oil, LPG, Natural Gas	CAES	CAES	Crude Oil, LPG, Natural Gas	Crude Oil, LPG, Natural Gas

consideration due to a lack of sufficient data on the salt geology (see Table 6-3). For the remaining 15 sites, discussed in some detail in Sections 7.0 to 10.0, the following conclusions can be summarized:

Port Richmond

Previous salt cavern development in the Port Richmond deposit revealed problems with insufficient capacity in one hole and unpredictable insoluble layers in the other hole. The complex nature of the deposit made prediction of the occurrence of the insoluble layers difficult. The depth of the deposit indicates that it would be suitable for the storage of all of the substances of interest. The close proximity of the Strait of Canso to the site probably makes this the best site in Nova Scotia for subsurface storage of crude oil and LPG, despite the problems that have occurred during development.

Shubenacadie-Stewiacke

Geologically, the Shubenacadie-Stewiacke site is the best salt unit in Nova Scotia with respect to cavern development. This relatively undeformed unit may be the largest salt deposit in Nova Scotia. It is well suited for storage of crude oil, liquefied petroleum gases, natural gas, and compressed air. However, the inland position of the unit leads to problems with access to markets, locating a water supply for solution mining, and disposal of the waste brine.

McIntyre Lake

The McIntyre Lake site, located 16 kilometres from the deep-water port at the Strait of Canso, has good potential for the storage of crude oil and LPG. The large size of the salt deposit will allow development of large storage cavities with corresponding economies of scale. Previous problems encountered with cavernous limestone and concerns regarding leakage through the upper strata should be resolved with more advanced drilling and engineering technology then was available during the previous work at the site.

Kingsville

Tests by Domtar (1978) have indicated that solution mining is a suitable means of extracting the salt from the Kingsville deposit. The deposit appears to be suitable for all substances of interest.

The site is well suited for storage of crude oil and LPG because of its proximity to the Strait of Canso and corresponding access to tanker shipments. However, development of the deposit at Kingsville will require the added cost of approximately 32 kilometres of pipeline which may make this site less attractive to develop.

Nappan

The depth, relative purity, and extensive thickness of the salt deposit at Nappan make it suitable for cavern development and substance storage. Its position near the Bay of Fundy makes it well suited for storage of compressed air energy from the proposed Fundy tidal power project.

Beaver Brook

The depth, thickness, and location of the Beaver Brook deposit near the Bay of Fundy make it a potentially suitable site for compressed air energy storage from the proposed Fundy tidal power project.

Boularderie

The Boularderie deposit consists of significant thicknesses of relatively high purity, relatively undisturbed salt. The site has good potential for cavern development for all substances of interest. Its location with respect to Sydney (70 kilometres away by land) and the proposed deepening of Bras d'Or Channel leading to the Atlantic Ocean may make this site economically attractive in the future.

Clarksville Occurrence

Geologic data collected suggest the presence of a large salt mass at Clarksville. The deposit could be suitable for CAES in conjunction with tidal power development, but requires further exploration and definition. The deposit is located approximately 24 kilometres east of a brackish portion of the Avon River which discharges into the Minas Basin.

Cleveland Deposit

The Cleveland deposit, located approximately 12 kilometres northeast of Port Hawkesbury, has potential for storage of crude oil and liquid petroleum gases. However, only one borehole (RC85-1) has been drilled to date. Further, deeper drilling is required to fully assess the potential of this deposit.

Estmire

The recently discovered Estmire deposit is located near St. Patricks Channel on Bras d'Or Lake. The massive salt deposit detected in the single borehole drilled at Estmire would potentially be suitable for storage of the substances of interest, but more drilling information is required to define the salt deposit.

Malagawatch

The structure of the Malagawatch deposit is relatively complicated. There is a confirmed thickness of 329 metres of salt which is considered to be relatively thin. The deposit has some potential for development of crude oil and LPG storage. It is situated along the western shore of Bras d'Or Lake and is approximately 40 kilometres northeast of Port Hawkesbury.

St. Patricks Channel

The St. Patricks Channel deposit, at McIvor Point on St. Patricks Channel of Bras d'Or Lake, is thick and complexly folded and deformed. There may be permeable limestone over the deposit. Further, drilling may indicate that the site has more potential than the existing data indicate.

Orangedale Deposit

The Orangedale deposit has potential for cavern development but data is lacking on total salt thickness. It is located approximately 2.5 kilometres south of the end of St. Patricks Channel.

Pugwash Deposit

The Pugwash deposit on the Northumberland Strait is extremely complex structurally and stratigraphically with many contorted near-vertical beds. Its complexity probably hinders its potential use for substance storage. The existing salt mine workings in Pugwash could be considered as storage sites when the mine is abandoned.

Malagash

The salt deposits at Malagash, on the shore of Northumberland Strait, are generally too thin or too deep for development.

The seven sites listed in Section 17.2 were selected as having the best potential for development. The eight sites thus eliminated on the basis of the selection criteria in 17.1 above may have future potential for storage if:

1. other substances are added;
2. new favourable geologic data is obtained; or
3. economic conditions change.

Thus, any of the eliminated sites may take priority over the currently "selected" sites, depending on further geologic investigation results, and on project-specific requirements (for example, those specified by a client seeking to store a particular substance within a given geographic area(s)).

19.0 REVIEW OF MOST SUITABLE SITES

19.1 General

The following sections summarize the discussion on each of the recommended sites:

19.2 Port Richmond

At Port Richmond, the depth to the top of the salt ranges from 250 to 550 metres below the ground surface. The bottom of the salt was found at between 600 and more than 1,550 metres depth.

The physical dimensions of this salt deposit lend themselves to a wide range of underground storage opportunities for a variety of substances. Based on borehole data and the Bouguer gravity map shown in Figure 9-3, a geological cross-section has been constructed (Figure 19-1) that depicts a salt mass about 2.5 kilometres in diameter and more than 1550 metres deep in its center. Most of the structure appears to lie beneath the shallow (10 to 20 metres deep) waters of Inhabitants Bay and Harbour. In general terms, we may consider the useful portion of the salt body as a cylinder, about 2.5 kilometres in diameter and about 950 metres in depth.

Figures 5-9 and 19-1 indicate the most suitable depth intervals for various substances. It would seem that this deposit would be suitable for storage of all of the above substances.

If the assumed useful portion of the Port Richmond salt cylinder is represented by the cross-section shown in Figure 19-1, the useful salt volume would be about:

1.375 km diameter x 300 m deep = 0.4×10^9 cubic metres, plus
2.5 km diameter x 950 m deep = 4.6×10^9 cubic metres
or 5 billion cubic metres of salt

If we further assume cylindrical caverns 600 metres tall arranged in a triangular pattern with a salt pillar/cavern diameter ratio of 2:1, the volume of extraction is:

Useable area (top of cylinder 2.5 km in diameter):	4,906,250 sq.m
Extraction ratio (triangular pattern):	10%
Areal extraction:	490,625 sq.m
Volume extraction:	294×10^6 cu.m

From the above, it can be seen that the maximum storage capability for this site is 294 million cubic metres (1850 million barrels) which is a suitable size for most storage requirements.

Water for solution mining is available from Inhabitants Bay. Waste brine can be discharged offshore through a bottom diffuser.

The Port Richmond deposit appears to be suitable for salt cavern storage. The main advantage of the site lies in its proximity to the deep water part of the Strait of Canso and the Gulf Oil Refinery. Disadvantages to the site include its complex stratigraphy and structure, and subsequently unpredictable insoluble layers.

19.3 Shubenacadie-Stewiacke

The Shubenacadie-Stewiacke salt deposit would provide an excellent site for the underground storage of crude oil, LPG, and natural gas.

The major limitations to the site are the lack of nearby water for solution mining and the potential difficulty in disposing of the brine.

Theoretically, water could be obtained from the Shubenacadie or Stewiacke Rivers and the brine could be injected into deep wells. As is discussed in Sections 11.4.3 and 12.0, there may be difficulties in obtaining sufficient water from these 'salmon' rivers during low-flow periods and deep-well brine disposal would require the permission of the Nova Scotia Minister of the Environment. The only feasible alternative to obtaining the solution mining water from the rivers is to pipe it in further downstream or the Minas Basin itself, which is 30 to 40 kilometres to the northwest. Brine could be piped to the Minas Basin for disposal or it could be used for production of salt, chlorine, etc. (Section 11.4.1). The high costs of pipeline installation and the lack of markets for the resultant large volume of salt products may make these options less attractive.

19.4 McIntyre Lake

Subsurface information from drillholes by Home Oil et.al. including Canso Strat No. 1 (Figure 9-4) indicate that there is a substantial thickness of salt within the depth interval 260 to 670 metres. The salt deposit is large and at a good depth for petroleum storage. However, thorough and careful exploration is needed before a suitable site for long-term underground storage can be selected. From the available geological data, the McIntyre Lake site appears to be inferior to the Port Richmond site for development of economic underground storage facilities.

Water for cavern development at this site can come from the Strait of Canso. Brine can be disposed of in the Strait of Canso through a surface diffuser. A 16 kilometre long pipeline will be required (Thomas et al., 1978).

The site is well suited for crude oil and LPG storage from an economic view point.

19.5 Kingsville

Twelve holes drilled by Domtar in the Kingsville area (Figure 9-1) have all intersected significant salt sections. The area of the Kingsville deposit is approximately one by three kilometres. The salt is approximately 540 metres thick in borehole 5 (Figure 9-2). Proven reserves are estimated to be 28.6 million tonnes (Domtar, 1968).

Water for cavern development at this site can come from the Strait of Canso with brine probably being disposed of through a surface diffuser. Home Oil and Gulf Canada Limited (1979) proposed to build a 16 kilometre pipeline from their McIntyre Lake site to the Kingsville site.

Like the McIntyre Lake site, the Kingsville site is well suited for crude oil and LPG storage because of its location with respect to the Strait of Canso. The economic viability of a project at McIntyre Lake may be enhanced by linked development of the nearby Kingsville deposit.

19.6 Nappan Deposit

The Sund No.1 borehole (Figure 8-1) indicates a halite section extending from about the 425 metre depth down to about 1,800 metres - with a salt thickness of approximately 1,350 metres. A Bouguer gravity map of the area (Figure 8-2) indicates an evaporite cross-section of about 4 kilometres. It appears that the usable salt reserve may have dimensions of at least 4 kilometres by 1,300 metres - for a conservative total of 16 billion cubic metres of salt.

It would appear that the deposit could technically support any kind of subsurface storage project. However, its only present economic viability appears to be for a CAES project in conjunction with a possible tidal power development.

Water for solution mining could be obtained from the mouth of the Nappan River or the Maccan River, both of which are saline near the Village of Nappan. These rivers discharge into the Cumberland Basin. Brine could possibly be disposed of in the river estuary or further out in the Cumberland Basin.

19.7 Beaver Brook

Limited data are available on the Beaver Brook deposit. The single borehole drilled into the salt (SD-2) found good quality salt within the depth interval 630 to 733 metres, and the bottom of the salt interval is thought (from the gravity survey, Figure 7-1) to be at a depth of 1000 to 1100 metres. A block of salt centered around the SD-2 borehole, has an apparent dimension of at least 1 by 4 kilometres and is at least 300 metres

thick. Accordingly, the volume of the deposit is at least 1.2 billion cubic metres.

Water for solution mining may be obtained from the Shubenacadie River 5 kilometres from SD-2. It may also be possible to dispose of the brine in the river which is very brackish at this point. The river is approximately 1.3 kilometres wide at its nearest point to the site.

The Beaver Brook salt deposit is much smaller than many of the other Nova Scotia deposits; careful exploration and evaluation will be required as a prerequisite to an actual site selection and storage cavern design. Moreover, based on the limited available data, there are apparently no low permeability (shale or clay) layers over the salt. However, the site may offer distinct advantages for CAES (in association with the Bay of Fundy tidal power project).

19.8 Boularderie

Only one borehole has been drilled on this site. The hole intersected salt 335 metres thick (Figure 10-1). The structural and stratigraphic conditions of the Boularderie deposit are relatively simple (Type A). This should simplify development.

Water for solution mining at Boularderie can be obtained from either Bras d'Or or St. Andrews Channel on either side of the peninsula. Similarly, brine can be disposed of in those water bodies.

The site would be suitable for storage of crude oil, LPG, and compressed air to serve Sydney and international markets.

20.0 GENERAL CONCLUSIONS

Based on the results of this study, it is evident that Nova Scotia has a strong economic and technical justification for major salt cavern storage applications. Chief among these is the opportunity to exploit the Sable Island area gas fields by use of compressed natural gas barge transport using salt caverns (and possibly coal mines) for surge storage. Installation of such systems would markedly improve Nova Scotia's economic future by providing a cheap, clean, indigenous fuel for both industry and consumers. The present study shows such a project to be

feasible. However, sharper definition is needed of expected competitive gas prices in New England and of total costs of Nova Scotia gas delivered by barge to that area. The maritime market is probably not large enough to support such a project on its own, although that too could be investigated.

With the signing of the Free Trade Agreement between Canada and the United States, trade with the Eastern Seaboard of the US is likely to increase. This area will be a good market for natural gas from the Venture Field.

The other major potential application for Nova Scotia salt cavern storage is a strategic hydrocarbon reserve. The US Congress is presently showing interest in providing the final 40 million cubic metres (250 million barrels) of crude oil storage required to complete the 160 million cubic metres (1 billion barrels) Strategic Petroleum Reserve. There are strong arguments why this last segment should be located on the east coast where it appears that Nova Scotia not only has near ideal sites but has the only sites suitable for subsurface storage.

In addition to the US need, Middle-East states have also expressed interest in crude oil storage in North America. This would provide for them a continued source of income in the event their own ability to deliver was curtailed.

Finally, the Canadian government may consider that it also has need for a petroleum reserve. The east coast of Canada depends almost entirely on imported crude. Since Canadian imports are small (1985 crude oil imports were 16 million cubic metres), the storage requirements would also be small. The impact on those affected by a cut-off is no less severe, however. Storage of refined product is also a need and cavern storage is a possibility.

Other opportunities for storage uses were investigated as well. Liquefied petroleum gas and compressed air energy storage have possible future application. These will depend on other developments like the Sable Island gas field to provide LPG or the development of tidal power. Compressed air energy storage may be an economically competitive form of generating peaking power and in combination with tidal power plants. However, CAES in conjunction with coal/oil fired plants would likely not be attractive. The use of liquid petroleum gases in Nova Scotia is

insufficient to justify the cost of developing salt cavern storage for this substance.

Therefore, the most immediate rewards will derive from crude oil and/or natural gas storage.

Determination of cavern size and number is not possible without previous determination of structural, economic, commercial, environmental, and operational criteria. Cavern size is an extremely site (and project) specific parameter. The useful depth interval for storage development is from 300 to 1800 metres (1000 to 6000 feet). Site conditions allowing a 950,000 cubic metres (6 million barrels) cavern is considered a reasonable, ultimate cavern size which should provide good structural stability at a low unit cost.

The total storage volume possible within a given surface area, complying with any reasonable spacing requirements, is essentially independent of the cavern diameter. The controlling factor in storage volume which can be created is, therefore, the cavern height. Based upon experience with oil storage caverns, 600 m (2000 feet) is usually the maximum practical cavern height. With the degree of interbedded insolubles and stratigraphic complexity typical of most Nova Scotian salt deposits the maximum practical cavern height would likely be somewhat less than this.

It is estimated that current (1988) storage development costs will range from \$17 to \$25 per cubic metre (\$2 to \$3 US per barrel). This cost per unit volume is independent of the size of the reserve being considered. It is dependent on the average volume of each individual cavern; larger caverns are more economical per unit volume to develop.

Costs indicated above represent guidelines only. Storage development costs are dependent on a number of factors, such as type of salt available; proposed development schedule; raw water acquisition system; brine disposal system; proximity of pipelines, terminals, and power sources. Costs are also affected by the specific nature of the storage; i.e. storage to serve a long-term emergency supply, commercial surge operations requiring relatively high fill and drawdown rates, etc. These questions must be settled on a site (and project) specific basis.

The level of detail in the geological data available for the various deposits is very uneven. Some of the sites have only been explored

by one borehole. Virtually none of the test holes were drilled to the lower-most part of the Windsor Group (Major Cycle #1) which characteristically contains the thickest and most pure salt layers (Boehner, personal communication). In addition, economical feasibility of underground storage is very project-specific.

At this time, a two phase program of further study can be visualized: the first phase is to delineate the complexity of the selected deposits and make a preliminary assessment of storage opportunities; the second phase to develop preliminary design regarding the promising area(s). Both of these phases require a better definition of the project requirements in terms of type of substance to be stored, purpose of the storage, storage volume, and schedule requirements.

The major environmental concern with respect to salt cavern storage is brine disposal. The impact of properly diffused brine disposal into the ocean is expected to be minimal. If conducted correctly at sufficient depths, the brine can also be disposed of by deep well injection.

Oceanic water can be used for solution mining at most of the selected sites. The only practical source of water at the Shubenacadie-Stewiacke site is the Shubenacadie or Stewiacke Rivers, both of which may have insufficient flows at low-flow periods to supply the estimated quantity of water for solution mining. Water storage would probably be required to maintain an economical brining flow rate and continuity.

21.0 RECOMMENDATIONS FOR FURTHER GEOLOGIC INVESTIGATION

It is recommended that further investigations be conducted at some of the sites as outlined below. Each of these deposits is considered to have potential for storage of the substances of interest to this study depending on its location with respect to the source and markets for those substances.

Port Richmond

A closely-spaced grid of high resolution seismic and gravity surveys should be implemented followed by more detailed drilling.

Shubenacadie-Stewiacke

Site specific evaluations should be conducted of the Shubenacadie-Stewiacke deposit. Drilling should be conducted on a more closely spaced grid.

McIntyre Lake

More deep drilling should be done. It is recommended that downhole geophysical logging be conducted and that a high resolution seismic survey be completed to help define the structural configuration.

Kingsville

High resolution seismic and gravity surveys should be conducted to provide targets for drilling through more pure salt sections.

Nappan

Further deep drilling should be conducted in the area of the NSDME holes 961 and 962 to establish the thickness, purity, stratigraphy, and structural relationships.

Beaver Brook

It is recommended that deeper drilling be conducted on the gravity minimum at the Beaver Brook site and that a high resolution seismic reflection survey be conducted.

Boularderie

At Boularderie, it is recommended that deep drilling and a detailed gravity survey and high resolution seismic survey be completed.

During all drilling programs, temperature and moisture data should be collected from boreholes and samples should be collected for rock mechanics tests to aid in cavern design.

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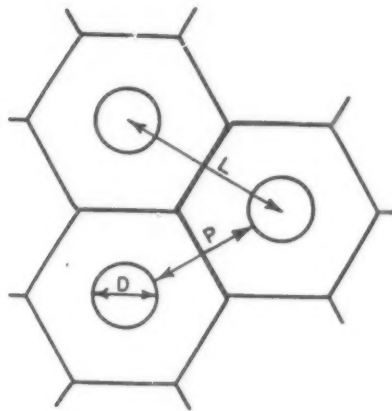
APPENDIX A

Correlation Between Cavern Size and Required Surface Area

APPENDIX A

Correlation Between Cavern Size and Required Surface Area

A hexagonal cavern spacing pattern presents the best use of surface area compared with any other pattern. The total area required for any size caverns is a function of the total volume of substance to be stored and the pillar thickness/cavern diameter ratio to be observed. The cavern height is assumed to be the same in any case. The following derivations prove the above statement. It must be remembered that these proofs are purely mathematical and that many influences such as specific configuration of available area may affect the actual placement of caverns in detailed design of a project.



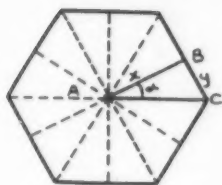
Nomenclature:

- D = Cavern diameter
- L = Distance between vertical centerlines of caverns
- P = Pillar Thickness
- R = P/D
- n = Number of caverns

Assumptions:

- (1) Caverns are right cylinders of length "H" (height) and diameter "D".
- (2) All caverns are identical.

Area of Hexagon



$$\text{Area } ABC = 1/2 XY$$

$$\text{and } Y = X \tan \alpha$$

$$\therefore \text{Area } ABC = 1/2 X^2 \tan \alpha$$

$$\text{Since } X = 1/2 L$$

$$\text{and } \alpha = \pi/6$$

$$\begin{aligned} \text{Area } ABC &= 1/2 (1/2 L)^2 \tan \frac{\pi}{6} \\ &= 1/8 L^2 \tan \frac{\pi}{6} \end{aligned}$$

$$\text{Area of Hexagon} = 12 \cdot \text{Area of } ABC$$

$$\text{Area}_{\text{hexagon}} = 3/2 L^2 \tan \frac{\pi}{6} \quad (1)$$

$$\text{Since: } L = P + D$$

$$P = R \cdot D$$

$$L = R \cdot D + D = (R + 1)D \quad (2)$$

Substituting Equation (2) into Equation (1):

$$\text{Area}_{\text{hex}} = 3/2 \tan \frac{\pi}{6} [(R + 1)D]^2$$

Area of Storage Site

Total Area of n hexagons:

$$\text{Area} = 3/2 \tan \frac{\pi}{6} [(R + 1)D]^2 (n) \quad (3)$$

Storage Volume

$$\text{Vol}_s = H \cdot \frac{\pi D^2}{4} (n)$$

Required Cavern Diameter

$$D = \left[\frac{\text{Vol}_s}{n H \pi} \right]^{1/2} \quad (4)$$

Where: Vol_s = Total storage volume (m^3)
 n = Number of caverns
 H = Height of caverns (m)

Substituting Equation (4) into Equation (3)

$$\text{Area} = \frac{3}{2} \tan \frac{\pi}{6} [(R + 1)]^2 \frac{\text{Vol}_s}{n H \pi} \quad (n)$$

$$\therefore \text{Area} = \frac{3}{2} \tan \frac{\pi}{6} [(R + 1)^2] \frac{\text{Vol}_s}{H \pi} \quad (4)$$

$$= 6 \tan \frac{\pi}{6} (R + 1)^2 \text{Vol}_s / H$$

$$\text{if } H = \text{Constant and } 6 \tan \frac{\pi}{6} / H = \text{Constant, } C$$

$$\text{then Area} = C(R + 1)^2 \text{Vol}_s \quad (5)$$

Inspection of Equation (5) reveals that the area required for the given caverns is a function of only the volume of substance to be stored (Vol_s) and the P/D ratio which one wishes to observe (R) and not a function of either the cavern diameter or number of caverns (which are direct functions of each other as shown in Equation (4)).

APPENDIX B

Data Forms

Preliminary Assessment of Available Geological Data

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area

OCCURRENCE OR DEPOSIT NAME: Beaver Brook Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1986) for New Senator-Rouyn and Peel-Elder

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY

Deposit is approximately 5 km X 1 km, based on a strong negative anomaly (16 m Gal).

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

Yes (Gamma Ray Log)

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Two

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Upper salt (35 m thick) located at 392 - 427 m. Lower (Main) Salt (at least 103 m thick, probably 300-450 m thick) located at 630.3 m (top of salt). Deposit is likely approximately 5 km X 1 km.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE NSDME (1968)

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 68.38% NaCl (Whole Rock)
89.63% in Soluble NaCl

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

397 m for Upper Salt (based on 2 boreholes)
360.3 m for Lower (Main) Salt (based on 1 borehole)

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, siltstone, limestone, dolostone, gypsum, anhydrite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized: good potential for further exploration and development

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Area originally investigated for potash potential by Wright (1931).
- Stevenson (1958) mapped the bedrock geology.
- Exploration drilling for gypsum (1956) near Hilden encountered native sulphur at shallow depths.
- NSDME drilled near same location in 1966.
- New Senator-Rough/Peel-Elder Corp. carried out more exploration and contracted NSRF to undertake a gravity survey of the area.
- A large negative Bouger gravity anomaly was delineated near Beaver Brook 6.5 km southeast of initial drilling.
- Salt was intersected on this gravity low in 1968 (NSDME 4735/50.2).

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Hants-Colchester Area
OCCURRENCE OR DEPOSIT NAME: Clarksville Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1986) for Scurry-Rainbow Oil Ltd.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY

Occurrence is approximately 5 km X 10 km, based on a large (30 m Gal) negative anomaly.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Three

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Insufficient data to determine thickness, extent of salt beds (87 m of steeply dipping salt were encountered in one borehole; probable true thickness of 44 m; 75 metres encountered in NSDME (1985) borehole. Potential further exploration and upgrading of occurrence to deposit status. May be connected to the Kennetcook occurrence, at depth.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

No, none in immediate area of occurrence, but some are reported in general area.

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

1974/HC-1: 271 m (Upper Salt) 358 m (Lower Salt)
1985/NSDME RC-85-1: 657 m (Lower Salt)

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, siltstone, gypsum, anhydrite, conglomerate, and sandstone

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized: good potential for further exploration and development.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Area originally mapped by Stevenson (1959) (1931).
- Borehole SR6-1 drilled in general area by Scurry-Rainbow (1966) on negative gravity anomaly in sulphur exploration work, but no salt encountered.
- Dresser Minerals (1967) drilled two boreholes (WS-1 and WCR-1) in general area with no salt reported.
- International Minerals and Chemical Corporation (1974) drilled Borehole HC-1 for potash, and penetrated brecciated, steeply dipping halite.
- Cominco (1981) carried out further potash exploration in the area but no drilling was involved.
- NSDME drilled RC-85-1 during fall/winter of 1985. Approximately 75 metres of salt intersected from 657 metres (top), then interbedded with ankydrite, shale, mudstone and pimestone.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area

OCCURRENCE OR DEPOSIT NAME: Falmouth Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouger Anomaly Maps 21 H/1E & 21 A/16E

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY

Poorly defined and very low relief negative anomaly.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Four

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Only a thin bed (3.35 m) of salt interbedded with anhydrite was encountered in drilling. The low relief Bouger anomaly suggests that the salt occurs only as thin beds or lenses of salt within the thick basal anhydrite unit.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE (Wright, 1931)

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 97% NaCl (Brine analyses)

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

165.5 m (based on 2 boreholes)

5.2 LITHOLOGY OF ENCLOSING STRATA

Gypsum and anhydrite interbedded with halite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized: not considered to be of economic importance

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Occurrence was originally discovered in four boreholes drilled by a private petroleum exploration company between 1911 and 1922.
- Wright (1931) summarized the findings based on these four boreholes.
- Falmouth No. 1 produced salt brine, Nos. 2 and 4 encountered approximately 3 metres of salt; and No. 3 encountered only anhydrite.
- More geological mapping of area occurred: Faribault and Fletcher (1909), Bell (1929, 1958), and Taylor (1969).
- NSRF gravity survey outlined a small, low relief negative Bouger anomaly.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area

OCCURRENCE OR DEPOSIT NAME: Kennetcook Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouger Gravity Anomaly Map 11 E/04, Leslie (1967)
(covers Upper Kennetcook area).

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Narrow, trough-shaped, negative anomaly (25 mGal).

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Yes

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Ten plus

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT

Seven (actual occurrence is defined by only one borehole: Anthony #3,
others are minor intersections)

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Structural configuration of the salt is unknown. The Bouguer minimum is
yet to be drilled; a large salt mass is inferred to the south and east of
the occurrence, but boreholes only intersected a 38 m salt thickness. May
be connected to the Clarksville occurrence, and further drilling could
establish a very extensive deposit.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Baar (1966)

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

404.5 m (Upper Salt, based on 6 boreholes)

409.3 m (Lower Salt, based on 1 borehole)

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, sandstone, siltstone, anhydrite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized. Not considered economical, but potential for other salt and potash deposits in the area exists.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Salt occurrence defined in Anthony No. 3 borehole (1944-45) by Nova Scotia Oil and Gas Company.
- Area was mapped by Stevenson (1959).
- SOQUIP drilled Noel No. 1 (petroleum exploration well) in 1975, 4.2 km northeast of Kennetcook and penetrated the entire carboniferous section without intersecting salt.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Hants-Colchester Area
OCCURRENCE OR DEPOSIT NAME: Shubenacadie-Stewiacke Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes
SOURCE? NSRF (1966) and St. Joseph Exploration subsequently.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?
Negative anomaly covers approximately 40 km x 15 km and has a magnitude of 20 mGal).

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Yes

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes
2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT 21 plus
2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT 21

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

The Stewiacke Formation (main salt-bearing unit) underlies an area between 42 and 50 km long and 6 km wide based on approximately 25 boreholes and gravity data. A large block of salt approximately 40 km long, 6 km wide and up to 300 m thick occurs in the central area of the basin.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes
SOURCE NSDME

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

None in immediate vicinity but one was reported in the northeastern end of the Stewiacke Valley (Cole, 1930).

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Cole, 1930

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT

87.47% NaCl (whole rock) based on 2 boreholes.

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

288.0 m

5.2 LITHOLOGY OF ENCLOSING STRATA

Limestone, dolostone, siltstone, sandstone, gypsum, anhydrite, calcareous clastics, conglomerate.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit not previously utilized, contains an estimated resource of 50 billion tonnes of 85% NaCl; very good potential for future exploration and development.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Salt potential in area originally noted by Hayes (1931) and Scott (1931).
- Many boreholes drilled by base metal exploration companies (during the 1970's) unintentionally intersected salt.
- Saint Joseph Exploration and Noranda carried out potash exploration in the area (Sangster et.al., 1975).
- Borehole SB-1 was drilled through the entire Windsor section by U.S. Borax (1976).
- Boreholes 153-1 (by Saint Joseph-Noranda) and SB-1 (U.S. Borax) were sampled and analyzed for purity of salt by NSDME.
- The deposit is defined by 5 deep and 14 shallower boreholes.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area

OCCURRENCE OR DEPOSIT NAME: Stanley Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1966) Bouger Anomaly Map 11 E/4

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Negative anomaly is approximately 6 km x 6 km, triangular in shape and has a magnitude of approximately 9 mGal.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Four

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Salt was only penetrated in one borehole at 350 metres depth. The hole was abandoned at 366 m in salt. Based on the limited data available, the occurrence is not considered economically important.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Yes, (Karst features 3 km west of SR-S-3)

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Baar (1966)

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

350.0 m

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, sandstone, gypsum, limestone, and anhydrite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence not previously utilized, not well-defined. Based on current level of knowledge, it is not economic, but requires more exploration to define limits of resource.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Hayes (1931) mapped the area in his Windsor Basin project.
- Stevenson (1959) also mapped the area as part of his Kennetcook map sheet.
- Two boreholes were drilled on a negative Bouguer Anomaly in 1966 by Scurry-Rainbow Oil in a sulphur exploration program.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area
OCCURRENCE OR DEPOSIT NAME: Sumnerville Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouger Anomaly Map 21 H/01E, NSRF Total Gravity Map (NSDME OFR 330).

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Small, low-magnitude positive anomaly associated with Windsor Group outcrop, probably related to high density anhydrite with minor interbedded salt.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Two

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Occurrence consists of minor inclusions or thin veins of salt within massive anhydrite; not considered significant or economic.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Karst topography, common in adjacent areas

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

No, but common in region

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

390 m

5.2 LITHOLOGY OF ENCLOSING STRATA

Gypsum, anhydrite, limestone

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence not previously utilized; potential for future development considered low.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- . Potash potential and regional geology described by Wright (1931).
- . New Jersey Zinc Corporation carried out a base metal exploration program in the area (1969) and drilled two boreholes intersecting only minor veins or inclusions of salt.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area
OCCURRENCE OR DEPOSIT NAME: Upper Walton River Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE NSRF Bouger Anomaly Map 11 E/04

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Occurrence area has no survey station, so anomaly is based on interpolated contours of widely scattered data; ill-defined, trough-shaped negative anomaly is apparent.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Nine

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Thickness and lateral extent of occurrence unknown, poor definition based on gravity and borehole data; the structure in the area is extremely complex with multiple repetitions of stratigraphy.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Yes; Karst topography common in area

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Cole, 1930

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

276.8 m (based on one borehole)

5.2 LITHOLOGY OF ENCLOSING STRATA

Conglomerate, sandstone, siltstone, limestone, gypsum, and anhydrite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence not currently utilized, structurally very complex; based on limited data available, has low potential for development.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Potash potential investigated by Wright (1931).
- Magnet Cove Barium Corp. drilled several deep holes in region (1969); defining another (Walton) occurrence to the south.
- Gulf Minerals Canada Ltd. drilled eight boreholes (1975) for base metal exploration, the deepest of which (GM-5) penetrated 11 metres of salt.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Hants-Colchester Area

OCCURRENCE OR DEPOSIT NAME: Walton Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1966) Bouger Anomaly Map 11 E/04W and 21 H/01E and
NSRF (1957) detailed gravity maps.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Widely spaced survey lines and complex geology probably resulted in
poorly defined anomalies (no definite pattern)

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Four

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Occurrence is poorly defined by both geophysics and borehole information.
Based on available data, it is not considered economically important.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Yes; Karst topography common in area

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Cole, 1930

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

382.0 m (based on three boreholes)

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, sandstone, limestone, gypsum, and anhydrite

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence not previously utilized, lateral extent and thickness of salt unknown, but based on available data not considered economically significant.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Potash potential investigated by Wright (1931).
- Salt water infiltrated nearby Walton Mine.
- General geology mapped by Crosby (1962).
- Detailed structural mapping by Boyle (1963, 1973).
- Magnet Cove Barium Corporation (Dresser Minerals) drilled four boreholes in general area (1967-69).

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area
OCCURRENCE OR DEPOSIT NAME: Beckwith Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1988) Bouger Anomaly Map 11 E/13 and Scurry-Rainbow Oil.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Broad circular anomaly, relatively strong; interpreted as a spherical body with a 2.0 km radius at a depth of 2.3 kilometres.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Five

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Main salt mass was not penetrated in drilling (only minor salt veins interbedded with shale), but large salt mass is probable based on gravity survey; interpreted anomaly suggests spherical body at 2.3 km depth with a 2.0 km radius.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Yes; Karst topography in area

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Unknown (main salt mass not penetrated - greater than 300 m, probably 450 to 600 metres).

5.2 LITHOLOGY OF ENCLOSING STRATA

Siltstone, shale, limestone, gypsum, conglomerate

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence not currently utilized; main salt body not penetrated in drilling but inferred from geophysics (very good potential for further exploration).

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Hayes (1931) initial reported on potash potential of Cumberland County.
- Scurry-Rainbow (1966) targeted a significant negative Bouguer gravity anomaly near Beckwith as part of their sulphur exploration program.
- Only one of five holes drilled intersected salt (associated with shale from 313 to 315 metres).
- Large salt body is interpreted to be at depth, based on gravity data.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area
OCCURRENCE OR DEPOSIT NAME: Malagash Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes
SOURCE? Miller and Norman (1936), NSRF (1967).

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Large, elongate negative anomaly coincides with Malagash-Clairmont Anticline. Triangular anomaly occurs near Wallace Harbour, to the west.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Yes

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes
2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Fifty +
2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Fifty +

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Elongate negative Bouguer gravity anomaly approximately 6 km x 1.5 km; also, broad triangular anomaly in East Wallace area, west of mine area (approximately 5 km diameter).

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No
SOURCE Ellsworth (1926), Chambers (1924), Hayes (1920); all included in Boehner (1986).

4.2 DISSOLUTION FEATURES REPORTED?

Yes, sink holes in general area.

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Cameron (1965), Cole (1930); both included in Boehner (1986).

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 94.91 - 98.47% NaCl Whole Rock (Ellsworth, 1926)

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Variance (approximately 30 metres to the top of mined salt beds: 800 to 1000+ metres to top of deeper, thicker salt section intersected in area west of mine).

5.2 LITHOLOGY OF ENCLOSING STRATA

Sandstone, shale, conglomerate, siltstone, gypsum, and anhydrite.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Underground salt mining was active here from 1919 to 1959. A total of 1.46 million tonnes of salt was mined. The deposit is not currently utilized; salt has been encountered in boreholes to the west of the previously mined area, but further drilling is required to determine the extent of the remaining salt reserves.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Interest in the area developed in the late 1800's with the discovery of salt springs and seeps.
- Salt water encountered at a depth of 25 m in a borehole drilled 11 km northeast of Malagash Station (1912).
- Twelve boreholes sunk in the area (1917) by Chambers and MacKay with salt brine intersected in six of the twelve at depths from 26 to 34.4 metres.
- A diamond drill hole and shaft (137 metres deep) were then sunk into the salt body.
- Further diamond drilling followed and defined an exploitable salt deposit.
- Commercial production of salt began in 1919 by the Malagash Salt Company.
- Small amounts of potash minerals were discovered in 1919.

- Mining, engineering and ore grade problems closed the mine in 1959.
- NSRF (1965-66) carried out a deep drilling exploration program for potash in the area. Four holes were drilled to the west of the mine site. In excess of 370 metres of salt was intersected in one borehole with some associated potash.
- Anschutz Corporation drilled Wallace Station No. 1 near Wallace Station in 1973 for petroleum exploration. The Windsor Group salt was intersected at 3981 to 4267 metres depth.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area

OCCURRENCE OR DEPOSIT NAME: Nappan Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouguer Anomaly Maps 21 H/09 and 21 H/16.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Rounded, approximately (4 km diameter) high magnitude negative anomaly.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Ten plus

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Five Plus

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Domtar's brining operation has extracted 3.3 million tonnes of salt since 1947. Total thickness of salt approximately 1400 metres in diapiric structure. Lateral extent of deposit not fully defined but gravity data and inferred geology suggest it underlies a broad area. Salt is approximately 96.6% NaCl below 600 metres.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE Imperial Oil (1932)

4.2 DISSOLUTION FEATURES REPORTED?

Yes, sink holes in area.

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT

Below 600 m = 96.6% NaCl (whole rock); above 600 m = less pure;
based on one borehole

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

307.6 m (based on five boreholes)

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, gypsum, anhydrite, limestone, sandstone.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit is currently being mined by brining (Sifto Salt Division of Domett Ltd.). The brining operation was started in 1947 by Maritime Industries. A total of 3.3 million tons of salt has been mined at the site. Extent of deposit is not well defined, but it appears to be very deep and extensive.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Minudie Anticline, which contains the Nappan salt deposit was explored for petroleum deposits by Imperial Oil Ltd. (1926-32) and Sun Oil Company Limited (1945-47).
- Salt water was reported in a well near Upper Nappan by Pohl (1931).
- Imperial Oil (1928) drilled six test holes near Nappan to confirm the nature of the Minudie Anticline.
- Four additional holes drilled (1929).
- One wildcat well drilled (1931) to a depth of 1260 m determined that the structure was not a simple anticline but rather a dome or diapiric structure with thicker core evaporites.
- NSDME studied the Nappan area in 1942 for possible extension of salt beds encountered in Imperial's wildcat well.
- Based on salt encountered in 2 of 3 wells drilled for NSDME program,

Maritime Industries began boring brine wells (1945) for evaporated salt production.

- Sunoco Nos. 1 and 1A drilled for petroleum exploration in area (1945-46), later taken over by Maritime Industries and used for brine production.
- Brining operation still in production (currently operated by Sifto Salt Division of Domtar Chemical Ltd.).

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area

OCCURRENCE OR DEPOSIT NAME: Oxford Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouguer Anomaly Map 11 E/12W

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Elipsoidal negative anomaly (>10 mGal) coincident with Windsor Group outcrop in core of structure.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Unknown

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Eight

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Orange halite veings and crystals encountered in some boreholes; mixed potash and salt at depth of 686 m in Borehole AOP-1, larger salt deposit inferred from gravity survey and recently confirmed with deeper drilling.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Not Available

4.2 DISSOLUTION FEATURES REPORTED?

Yes, many lakes in area occupy sink holes (Bell, 1944).

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE?

Yes, also salty drilling water analyses.

SOURCE Cole (1930), Hayes (1931)

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Approximately 100 m to mixed halite/mudstone/anhydrite (3 boreholes); 686 m to salt/potash (1 borehole).

5.2 LITHOLOGY OF ENCLOSING STRATA

Gypsum, sandstone, shale, mudstone, anhydrite.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit currently not utilized, requires further drilling to establish size, extent of salt deposit.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Very saline salt springs and ponds reported by Hayes (1931) and Bell (1944).
- Several boreholes drilled by a private concern prior to 1931 intersected nearly vertical Windsor Group gypsum and shale.
- Salt water returned from the drill holes was analyzed by the Canada Department of Health (Hayes, 1931).
- Malagash Salt Company Ltd. drilled two drill holes southeast of Oxford in 1952; small amounts of salt were intersected in one of the holes.
- Amax Potash Ltd. drilled two other holes nearby in 1979, intersecting salt mixed with mudstone and anhydrite. Some potash was reported from one of the boreholes.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area

OCCURRENCE OR DEPOSIT NAME: Pugwash Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1964) Bouguer Anomaly Map 11 E/13 E

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Elongate 6 mGal negative, anomaly follows outline of Windsor Group outcrop area.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

Yes, NSRF (1963) Gamma Ray Log BH CRSC-59.

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT 30 +

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT 30 +

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

More than 17 million tons of salt have been mined by conventional underground methods since the operation began in 1959. Salt deposit first encountered at 100 to 130 metres depth and underlies approximately 3.0 x 0.8 kilometre section of Windsor Group outcrop area.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE Baar (1966)

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE Not Available

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Variable

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Approximately 115 metres (based on 15 drill holes).

5.2 LITHOLOGY OF ENCLOSING STRATA

Anhydrite, mudstone, sandstone, shale.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit has been mined by an underground modified room-and-pillar method since 1959. Over 17 million tons of salt have been mined. Estimated resources, based on a 50 percent halite content in a block 3000 m long, 800 m, wide and 300 m thick to maximum depth of 500 m indicates approximately 800 million short tons of unknown grade.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Pugwash area first investigated as part of a regional potash study by Hayes (1931).
- Bell (1944) suggested the area had little salt or potash potential because the salt zone was submerged beneath the Pugwash River estuary.
- Salt was first discovered in a well drilled for water in 1953 at a depth of 137 metres.
- Malagash Salt Company began sinking a shaft in the area (1956) based on the successful intersection of salt in several drill holes which were drilled in 1954.
- The shaft was 219.5 metres deep with a development level at 192 metres in 1959 when the mine was officially opened (November 4, 1959).
- The Malagash Mine closed the same year due to the mining and ore grade problems.
- Reserve estimates at the new mine were placed at 200 million tons.

- The Malagash Salt Company reorganized in 1961 to become the Canadian Rock Salt Company Ltd. and began a new drilling program to further explore the deposit.
- A new production shaft was started in 1962, and the present operation is producing salt at the 250 metre level.
- Pacific Petroleum Ltd. drilled Pacific Fox Harbour C-96V, 10.5 kilometres east of the Pugwash Mine in 1963. It was located on the eastern extremity of the Minudie Anticline, the structure which contains the Pugwash salt deposit. Salt was not intersected until 2678 to 2856 metres, with salt and shale occurring from 2966 to 2981 metres.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Cumberland Area
OCCURRENCE OR DEPOSIT NAME: Roslin Occurrence

1.0 GEOPHYSICAL DATA

- 1.1 GRAVITY SURVEY AVAILABLE? Yes
SOURCE? NSRF (1966) Open File Report 049
- 1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?
Approximately 3.5 kilometre diameter rounded negative anomaly of moderate strength.
- 1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

- 2.1 BOREHOLE LOGS AVAILABLE? Yes
- 2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT One
- 2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Unknown.

4.0 GEOCHEMICAL DATA

- 4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No
SOURCE
- 4.2 DISSOLUTION FEATURES REPORTED? No
- 4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes
- 4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes
SOURCE Cole (1930)

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Unknown, (presence indicated by gravity survey).

5.2 LITHOLOGY OF ENCLOSING STRATA

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Small, complex diapir with salt mass at depth. Based upon available data, not considered to be of economic interest.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- NSRF Bouguer anomaly map.
- Bidgood (1970) Gravity Modelling on above.
- NSDME & NSRF Geophysical; Geological Survey's drilling ('65-'66) Potash Exploration.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: Cleveland Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1:31, 680)

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY? Unknown

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Unknown

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT One

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

**3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA**

Salt intersected at 732 metres - 1054 metres.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE

4.2 DISSOLUTION FEATURES REPORTED? Yes

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

No, (some, regionally)

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

732 m based on 1 borehole.

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, sandstone, limestone.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Unknown.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Noranda Exploration Co. Ltd. recently (1981) drilled one hole (N227-2) which intersected salt at 732 m to 1054 metres.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: Kingsville Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF Bouguer Anomaly Map Ehycomagh (Domtar, 1967).

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Deposit is approximately 1 x 3 km (measured from map); high amplitude (16 mGal) Bouguer anomaly low.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

Yes, Domtar Project; Gamma Ray Logs were run in each hole after coring. In addition (K-12), in one borehole a velocity log was run.

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Eleven

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Ten

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Hole No. 5 - salt 540 m thick; proven salt reserve (Domtar Ltd., 1968) estimated 28.6 million t; estimated probable reserves adjacent to drilled area of approximately 1.04 billion t.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE?

Yes; not available at time of report.

SOURCE NSDME

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Domtar

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 90% NaCl Average whole rock

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Salt intersected at 397 m in Hole #3; salt intersected at 494 m in Hole #4.

5.2 LITHOLOGY OF ENCLOSING STRATA

Siltstone, mudstone, shale, sandstone, conglomerate, gypsum, anhydrite, halite, limestone, an dolostone.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Domtar considered the deposit for possible development of underground salt caverns for petroleum storage. Situated approximately 20 km north of the ice-free deep water port facilities on the Strait of Canso. Not currently utilized.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Earliest reference to salt in the area was made in 1869 by How (Report 4, Salt Springs).
- 1931 Hayes investigated Cape Breton for salt and potash - no salt springs were found in the Kingsville area.
- 1967 NSRF did gravity survey, revealing a gravity anomaly at Kingsville.
- Domtar drilled 11 holes between 1968 and 1971 because of the significant Bouguer gravity anomalies.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: McIntyre Lake

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF (1967, 1971) gravity surveys. NSRF (1971) survey maps were used by Airborne Geophysics Surveys Ltd. in a gravity interpretation for Murphy Oil Co. Ltd. In 1970 a gravity survey was conducted by Overland Exploration Services Ltd. for Murphy Oil Co. Ltd.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Anomaly not well defined; elongated, approximately 12 mGal-7 x 10 km.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

Yes, NCO Canso Strat No. 1 (gamma ray caliper logs); NCO Canso Strat No. 2 (gamma ray, micro-caliper and gamma-gamma (density) logs. Four drillholes by Home Oil - unknown if geophysical logs available.

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Six

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Six

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Salt Hole 1 - 574 metres thick; Salt Hole 2 - 661 metres with intermittent claystone, anhydrite, and limestone.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE "Salt & Potash Res. in Nova Scotia" Boehner pg. 213 & 21; Port Hawkesbury-McIntyre Lake area, Inverness County, Cape Breton - NSDME report 11F/11C 42-J-68(01).

4.2 DISSOLUTION FEATURES REPORTED?

Not in McIntyre Lake, but several were reported in the Dundee-West Bay area approximately 15 km northeast (although they were not found by Ferguson, 1946).

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE?

SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 85% NaCl Average (whole rock)

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Canso Strat No. 1 intersected salt at 256.6 m (pg. 209 - Salt Report);
Canso Strat No. 2 intersected salt at 255 m (pg. 206 - Salt Report).

5.2 LITHOLOGY OF ENCLOSING STRATA

No. 1 - siltstone, gypsum, limestone, shale, anhydrite.
No. 2 - gypsum, clay, anhydrite, limestone, shale.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit comprised of halite with local, thin (less than 30 cm) potash salt zones with K₂O analyses of up to 14 percent. Geology and geophysics together indicate the possibility of potentially a large salt deposit. An accurate estimate of reserves is pending the completion of further experimental work by Home Oil (who have been exploring for potential development of solution mined underground storage structures). It is located close to the Strait of Canso (ice-free; capable of handling VLCC).

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Late 1960's, Bouguer gravity surveys outlined high amplitude gravity lows in the area.
- 1972-1974 Murphy Oil Co. Ltd. and Northern Canadian Oils Ltd. explored by diamond drilling - establishing the presence of a major salt deposit.
- 1978 - Home Oil Canada Ltd. conducted further exploration and drilling.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: Malagawatch Deposit

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? Unknown

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY? Unknown

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? Yes, Chevron

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Nine

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT

**3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA**

Approximately 1.0 x 3.0 km gravity anomaly.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE NSDME - Salt Report (Boehner, 1986).

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

No, (some, regionally)

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Not Available

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

230 metres.

5.2 LITHOLOGY OF ENCLOSING STRATA

Limestone, anhydrite, mudstone, potash.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- 1978, Chevron Standard Ltd. unexpectedly encountered light crude oil in base metal exploration drilling near Malagawatch.
- The area became a petroleum prospect and was drilled in 1980 under a joint venture between Chevron Standard Ltd. and the Irving Oil Co. Ltd.
- The third well drilled unexpectedly intersected a significant section of salt and potash. The area then became a promising potash prospect.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area
OCCURRENCE OR DEPOSIT NAME: Orangedale Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes, pp. 194, 212 Salt Report (Boehner)
SOURCE? Pages 194 and 212 of Salt Report - NSDME Boehner; 1972 NSRF (Gravity Data); 1967 Domtar Ltd.; page 218 of Salt Report, Boehner; 1978 - Bouguer gravity after Noranda Exploration Company Limited.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?
12 km x 12 km (approximate); approximately 12 mGal.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes
2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Five
2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Unknown

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No
SOURCE
4.2 DISSOLUTION FEATURES REPORTED? Yes
4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes
4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No
SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Unknown

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

300 metres (variable from 170 to 600 metres)

5.2 LITHOLOGY OF ENCLOSING STRATA

Limestone, anhydrite, shale, mudstone.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- 1931, Hayes did regional survey for salt including this area.
- 1977/78/79, Noranda Exploration Co. Ltd. did geophysics and geochemical studies then drilled an exploration hole midway between Orangeville and Whycocomagh (on the Northeast flank of a large Bouguer gravity low) and intersected a highly brecciated salt-bearing section (between 610 and 892 m).
- 1978, following the significant potash finds in Malagawatch by Chevron, exploration was extended and four more holes were drilled across the Bouguer low.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: Seaview Occurrence

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF 1967 - Residual Anomaly Map - Lennox Passage

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Approximately 5 mGal; approximately 8 km x 4 km.

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No.

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? 1968 Dometar drilled one hole

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT One

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

**3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA**

Salt intersected at 732 metres - 1054 metres.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE

4.2 DISSOLUTION FEATURES REPORTED? No

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? Yes

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Unknown

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

500 m

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, siltstone breccia, Windsor Group

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Occurrence consists of halite in veins and in association with shale-siltstone breccia. Salt spring possibly related to bounding fault (2 km north of Seaview No. 2). Bouguer anomaly may be caused by Windsor Group adjacent to fault. Although salt was encountered in No. 2, it was not of economic importance.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- 1931, Kindle investigated the Seaview area for salt and potash potential. Several salt springs and seeps were located at depth.
- 1967, NSRF did gravity survey.
- 1968, Domtar drilled on a Bouguer gravity low outlined by NSRF (1967).

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: St. Peters

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? NSRF 1967 - bouguer Anomaly Map (Lennox Passage) for Domtar Ltd.

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Approximately 3 x 4 km - 12 mGal (pg. 225)

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes, Domtar Ltd. drilled 1968 - see NSDME Salt Report (Boehner) pg. 224.

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Two

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Two

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Drilled holes show siltstone with salt veins for 100 m then pink halite with variable abundant shale for another 8 m when the hole was ended. Second hole encountered similar stratigraphy to total depth of the 925 metres. Main salt mass inferred at greater depth.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No

SOURCE Salt seepage along fault line

4.2 DISSOLUTION FEATURES REPORTED? Yes

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT?

Salty seepage noted along fault in region.

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? No

SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT Unknown

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

Approximately 500 metres.

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, siltstone, gypsum.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Halite associated with shale and siltstone breccia. Large part of the salt as inferred from the anomaly map, probably occurs beneath St. Peters Bay. Exploration to date has not been encouraging. The deposit will need further exploration to determine its economic significance.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- 1967 - NSRF did gravity survey over area outlining an anomaly in the area.
- 1967 - Domtar Ltd. selected the St. Peters area for salt exploration due to the gravity anomaly.
- 1968 - Drilled two exploratory holes, St. Peters Nos. 1 and 2 (Domtar); found salt in both.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Canso-Bras d'Or Area

OCCURRENCE OR DEPOSIT NAME: Port Richmond

1.0 GEOPHYSICAL DATA

1.1 GRAVITY SURVEY AVAILABLE? Yes

SOURCE? Ref. Salt Report, NSDME (Boehner); 1972 - NSRF Bouguer
Anomaly Map - River Inhabitants

1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?

Approximately 4 km (Windsor Group) anomaly; approximately 8 sq. km-
30 mGal (pg. 221)

1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?

Yes, NSRF (1967-68) on Port Richmond Nos. 1, 2, and 3.

2.0 BOREHOLE INFORMATION

2.1 BOREHOLE LOGS AVAILABLE? Yes

2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT

Approximately 12; Brine well - 1 (pg. 219 Salt Report)

2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT Approx. Five

**3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA**

DCPR-1 - >255 m salt; DCRR-2 - 94 m salt; CIL-1 - >450 m salt;
DCRP-3 - 1052 m began in salt and ended in salt veined sandstone.

4.0 GEOCHEMICAL DATA

4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? Yes

SOURCE Salt Report pg. 220 and pg. 306-308

4.2 DISSOLUTION FEATURES REPORTED?

4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No

4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Yes

SOURCE Salt Report (Boehner) pg. 307

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 85% NaCl Average (whole rock)

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

130 m (salt veins in siltstone - main salt not intersected).

5.2 LITHOLOGY OF ENCLOSING STRATA

Shale, quartzite, conglomerate, carnallite, anhydrite, limestone, siltstone.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Deposit defined by 5 deep exploratory wells; 30 mGal - Bouguer gravity anomaly. Significant salt sections (exceeding 1000 m); Dow Chemical Co. Ltd. proceeded with the development of brined caverns for possible underground storage in the DCPR-11P and 12P until 1976 when the project was placed in deferement.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- 1965 - NSRF found high amplitude negative Bouguer gravity anomaly.
- 1967 - Exploration by Dow Chemical Co. of Canada and Dew Mining Corporation Ltd.; Dow conducted gravity survey and 2 diamond drill holes.
- 1972 - 5 deep exploratory holes intersected salt sections; 7 shallow holes were drilled to obtain structural and stratigraphic information.
- 1973 - A brining well DCPR-11P was drilled.
- 1973-1976 - Test caverns were developed.
- 1975-1976 - A second brining well was drilled (DCPR-12P) and test cavern developed.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

**(Additional Salt Deposits/Occurrences Recently
discovered in the Canso Bras d'Or Area)**

Estmere Deposit

Noranda Exploration Company Limited drilled a hole (N227-1) near Estmere in 1981 and intersected salt from 399 metres to the total depth of 860 metres (Baechler, 1986).

St. Particks Channel Deposit

Drillhole R1/R1W (drilled by Chevron Standard Limited in 1980), located 25 kilometers northeast of the Orangedale deposit, intersected salt from 396.5 to 1174 metres depth.

**PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA**

GEOGRAPHICAL AREA: Sydney Area
OCCURRENCE OR DEPOSIT NAME: Boularderie Deposit

1.0 GEOPHYSICAL DATA

- 1.1 GRAVITY SURVEY AVAILABLE? No
SOURCE?
1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY? No
1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE? No

2.0 BOREHOLE INFORMATION

- 2.1 BOREHOLE LOGS AVAILABLE? Yes, NSDME Kempt Head 84-1.
2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT One
2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

**3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON
AVAILABLE GEOPHYSICAL AND BOREHOLE DATA**

Salt 335 m - First 190 metres is low grade (70% NaCl) with mudstone, the
dominant impurity; the rest 145 m are 90 - 95% NaCl.

4.0 GEOCHEMICAL DATA

- 4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No
SOURCE
4.2 DISSOLUTION FEATURES REPORTED? No
4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No
4.4 SALT SPRING BRINE ANALYSES AVAILABLE?
SOURCE
4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT 90-95% NaCl (whole rock)
(based on one drillhole)

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

495 m (based on 1 hole)

5.2 LITHOLOGY OF ENCLOSING STRATA

Sandstone, siltstone, mudstone, limestone, dolostone, anhydrite, gypsum.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Further drilling and gravity surveys will be required to assess the extent and significance of the salt deposit.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Deposit was discovered in a stratigraphic test hole (NSDME, Kempt Head 84-1) drilled by NSDME in 1984.

PRELIMINARY ASSESSMENT OF
AVAILABLE GEOLOGICAL DATA

GEOGRAPHICAL AREA: Sydney Area
OCCURRENCE OR DEPOSIT NAME: East Bay Occurrence

1.0 GEOPHYSICAL DATA

- 1.1 GRAVITY SURVEY AVAILABLE? No
SOURCE?
- 1.2 AREAL EXTENT AND STRENGTH OF BOUGER ANOMALY?
- 1.3 DOWN HOLE GEOPHYSICAL LOGS AVAILABLE?
Yes, NSRF (1967-68) on Port Richmond Nos. 1, 2, and 3.

2.0 BOREHOLE INFORMATION

- 2.1 BOREHOLE LOGS AVAILABLE? Yes
- 2.2 TOTAL NUMBER OF BOREHOLES IN VICINITY OF OCCURRENCE/DEPOSIT Three
- 2.3 TOTAL NUMBER OF BOREHOLES WHICH PENETRATE SALT One

3.0 SUMMARY OF ESTIMATED EXTENT OF SALT DEPOSIT OR OCCURRENCE, BASED ON AVAILABLE GEOPHYSICAL AND BOREHOLE DATA

Minor salt intersection (<3 metres) in one drillhole. Potential for more salt deeper within synclinal structure.

4.0 GEOCHEMICAL DATA

- 4.1 WHOLE ROCK CHEMICAL ANALYSES AVAILABLE? No
SOURCE
- 4.2 DISSOLUTION FEATURES REPORTED? No
- 4.3 SALT SPRINGS REPORTED IN VICINITY OF SALT OCCURRENCE/DEPOSIT? No
- 4.4 SALT SPRING BRINE ANALYSES AVAILABLE? Not Available
SOURCE

4.5 AVERAGE GRADE OF OCCURRENCE/DEPOSIT

25% NaCl intermixed with anhydrite, limestone, sandstone.

5.0 ENCLOSING STRATA

5.1 AVERAGE THICKNESS OF OVERLYING STRATA (SURFICIAL MATERIAL AND ENCLOSING STRATA)

284 m

5.2 LITHOLOGY OF ENCLOSING STRATA

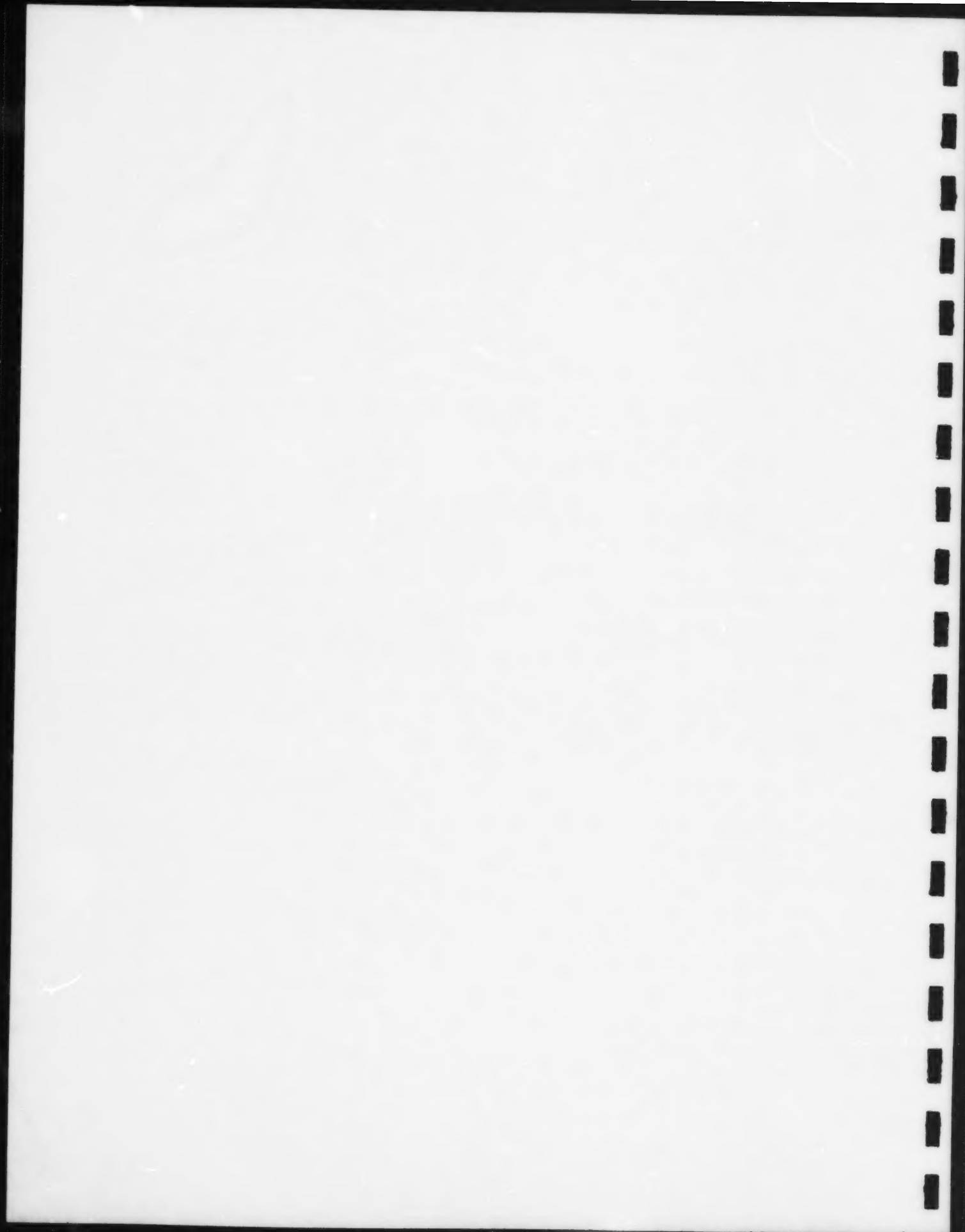
Limestone, gypsum, anhydrite, sandstone, conglomerate.

6.0 STATUS/PRIOR UTILIZATION OF OCCURRENCE OR DEPOSIT

Not currently utilized; considered to be of little economic significance but has potential for further (deeper) exploration.

7.0 SHORT HISTORY OF EXPLORATION AND DEVELOPMENT OF OCCURRENCE/DEPOSIT

- Morton Chemical of Canada Limited undertook first exploration for salt in area (1961-62).
- Bell (1961) described basic geology and stratigraphy of area.
- Three drillholes (NSDM 3439, 3440, 3630) drilled by Morton Chemical of Canada Limited in 1961.



APPENDIX C

Environmental Features of Selected Sites

APPENDIX C

ENVIRONMENTAL FEATURES OF SELECTED SITES

C.1 Climate, Forest, and Endangered Species

Despite its maritime location, Nova Scotia has essentially a continental type climate. However, locally the presence of the sea can have major climatic influences. The outer coast of Nova Scotia is markedly cooled in the summer by the cold water of the Labrador current. In the winter along the coast, the climate is mild, warmed by the relatively warm ocean. The prevailing wind direction is from the west. Cyclonic storms tracking from the west cause a wide variation in temperature from day to day and from season to season. Precipitation is usually abundant and reliable throughout the entire region. Summers are relatively short. Temperatures average over 16 degrees Celsius from the latter part of June until the end of August. Storm activity increases in the fall, resulting in more precipitation. Temperatures usually drop below freezing by November and remain on average below freezing until early April, although above-freezing temperatures (and rain) occasionally occur in the winter months. Less snow falls in Nova Scotia than in the other Maritime Provinces because of the influence of warmer sea air. In these areas, the precipitation falls as rain. Spring arrives gradually in Nova Scotia. Mean temperatures are in the 2 to 4 degrees Celsius range in April and reach 10 to 14 degrees Celsius by late May. There is often a strong temperature gradient between the warm interior and the relatively cool coastal areas during the spring season (Hare and Thomas, 1974).

The selected sites all lie within the Acadian Forest Region. The most common trees which occur in the forest in this region are red spruce, balsam fir, yellow birch, sugar maple, red pine, eastern white pine, and eastern hemlock. White spruce, black spruce, red oak, white elm, red maple, white birch, grey birch and poplar also occur (Hosie, 1979).

Endangered or rare species of ferns, flowering plants, snails, bivalves, salamanders, and bats have been noted to occur near several of the sites (see Table C-1). Endangered plant species such as the Ostrich Fern, which grows beside streams and near limestone and gypsum outcrops, may be of concern at all of the salt cavern sites.

C.2 Port Richmond

Port Richmond is located within the Atlantic Uplands (Clayton et al., 1977). The maximum elevation change on the site near Jimmy's Point is 15 metres (Figure 17-1). A single, 0.8 kilometre-long, unnamed stream occurs on Jimmy's Point. The stream drains toward the west-northwest to MacNamara's Cove.

Surficial material at the Port Richmond site is a stoney, gritty clay to silt till (Nova Scotia Department of Development). Soils consist of a Gray Luvisol (Clayton et al., 1977). Luvisols are one of the main soil types in Canada. They develop under the influence of the growth and decomposition of Boreal forest vegetation in mild to cold climates. The Luvisols have mostly developed on glacial till and glaciofluvial or glaciolacustrine deposits. They tend to be medium textured soils with some clayey soils. Luvisol soil characteristics rarely develop in the coarser sandy soils. Agricultural soil survey maps describe the soil as a dark reddish-brown clay loam till (Cann et al., 1963).

C.3 Shubenacadie-Stewiacke

The Shubenacadie-Stewiacke area is located within the Atlantic Uplands (Clayton et al., 1977). The topography consists of gently rolling hills with elevations rarely exceeding 75 metres. Soils consist of Grey Luvisols (Clayton et al., 1977). Agricultural soil survey maps describe the soil in the area as a dark reddish-brown loam to sandy clay loam (MacDougall et al., 1963). Well logs suggest an average soil depth of 19 metres.

The deposit lies within the Shubenacadie River and the Stewiacke River watersheds. The Stewiacke River may be considered to be the second-most important "Salmon River" in Nova Scotia (Lewis, 1988).

Communities which lie within the deposit area include Brookfield, Stewiacke, Shubenacadie, Elmsdale, Middle Musquodoboit, and Upper Stewiacke. Stewiacke, with a population of 1174 (in 1976), obtains its water through an infiltration gallery set in the bed of the St. Andrews River (Nova Scotia Department of Municipal Affairs, 1981b). The water supply for Shubenacadie which had a population of 704 in 1976 is Snides Lake (ibid). Some attempts have been made to obtain groundwater supplies in the Shubenacadie area. There are records of 18 wells drilled in the area. The well depths average 34 metres and range from 6.7 to 68.6 metres.

The main economic activity in the area is farming.

C.4 McIntyre Lake

Soils at the McIntyre site consist of a Gray Luvisol (Clayton et al., 1977). Luvisols are one of the main soil types in Canada. They develop under the influence of the growth and decomposition of Boreal forest vegetation in mild to cold climates. The Luvisols have mostly developed on glacial till and glaciofluvial or glaciolacustrine deposits. They tend to be medium textured soils with some clayey soils. Luvisol soil characteristics rarely develop in the coarser sandy soils. Agricultural soil survey maps describe the soil as a dark reddish-brown clay loam till (Cann et al., 1963). Well logs suggest that the average soil depth is about 12 metres.

McIntyre Lake is located within the Atlantic Uplands (Clayton et al., 1977). It drains to the southwest into the North Little River. It lies at an elevation of approximately 53 metres.

The 1:50,000 1980 topographic map sheet for the area (11F/11) shows 21 buildings within a kilometre of McIntyre Lake. There is no agricultural activity near the site. Water for domestic use appears to be drawn from relatively shallow drilled wells and possibly dug wells. There are records of 7 domestic wells drilled near McIntyre Lake. The average well depth is 30 metres. Well depths range from 18 to 64 metres.

C.5 Kingsville

Agricultural soil survey maps describe the soil in Kingsville as a dark reddish-brown clay loam till (Cann et al., 1963). West of the Kingsville-Riverside Road to the south of Kingsville, the soil is a glaciofluvial deposit of clay, silt and fine sand (Nova Scotia Department of Development).

Kingsville is located within the Atlantic Uplands (Clayton et al., 1977). The village lies on the eastern side of the broad flat flood plain of River Inhabitants which drains to the southwest. The floodplain is 3 to 4 kilometres wide and has a maximum elevation change of 30 metres. To the west of the River Inhabitants is McIntyre's Mountain which rises to at least 275 metres above sea level.

The 1:50,000 1979 topographic map sheet (11F/14) for the area shows 13 buildings within the village. Some agricultural activity occurs in the area. There are no published records of wells drilled in Kingsville.

C.6 Nappan

Nappan, located in the Maritime Plain Region (Clayton et al., 1977) has Gray Luvisol soils. Agricultural soil surveys describe the soil as a "sandy loam" (Whiteside et al., 1945). Vaughan and Somers (1980) indicate that the parent soil is peat and muck. The average depth of soil determined from well drilling records is 13 metres.

Nappan lies within the marshy lowlands which lie between Nova Scotia and New Brunswick. Elevations within this area rarely exceed 30 metres and are frequently at or near sea level. Nappan is located near the mouth of the Nappan River. This river drains to southwest to the Maccan River which, in turn, drains into the Cumberland Basin.

In Nappan, there are approximately 20 homes and a school and church. The area is almost entirely agricultural. The Maritime Beef Cattle Test Station is situated on the southern end of the community. The Chignecto National Wildlife Area is located in a marsh approximately two kilometres northwest of Nappan. The Sifto Salt Company runs a brining operations just north of the community.

The water supply for Nappan homeowners consists of individually-owned dug wells and shallow drilled wells. There are records of five drilled wells in the community. The average well depth is 18 metres and ranges for 6.7 to 27.4 metres.

C.7 Beaver Brook

Beaver Brook, located in the Maritime Plain Region (Clayton et al., 1977), has Gray Luvisol soils. Agricultural soil survey maps describe the soil as light brown loam to clay loam over yellowish brown clay loam (Wicklund and Smith, 1948). The soil is often strongly mottled indicating poor internal drainage.

There are approximately 20 houses, one church, and one greenhouse in the community of Beaver Brook. The area is primarily agricultural and residential. Homeowners in Beaver Brook utilize drilled wells. Homeowners closer to the borehole location (Section 7.2) are primarily on dug wells.

The community of Beaver Brook lies at the confluence of Beaver Brook and an unnamed stream. Beaver Brook drains to the north to Cobequid Bay. At the community, the brook was approximately 4.5 metres wide and one metre deep at the time of a site visit (88/03/25). The stream flow rate was approximately 0.9 cubic metres per second.

The terrain is moderately undulating. The grade in the area is approximately 6 percent from the west and east towards Beaver Brook.

The two boreholes that have been drilled are located approximately six kilometres south of the community (Figure 7-1a).

C.8 Boularderie

Boularderie Island is located within the Atlantic Uplands (Clayton et al., 1977). The "Island" is actually a peninsula running southwest-northeast in Great Bras d'Or Lake (Figure 17-1). It borders Great Bras d'Or to the north and St. Andrew's Channel to the south. Maximum elevation near the site at Kempt Head is 107 metres. The ridge-like peninsula is approximately 9 to 11 kilometres wide.

Bodies of water on Boularderie Island include MacKay's Pond, MacEachern's Brook, MacEachern's Pond, MacPhee's Brook, Black Brook, Aconi Brook, and Patterson's Lake. The brooks run southeast-northwest down the centre of the island, and down the southeastern part of the peninsula.

Soils consist of Humo-Ferric Podzols (Clayton et al., 1977). Humo-Ferric Podzols occur mainly on well-drained sites and are found in cool Boreal and Cryoboreal humid to perhumid climates. They usually occur over coarse-textured, iron-rich, non-calcareous parent materials.

The peninsula is sparsely populated with little or no agricultural activity.

TABLE C-1

Rare and Endangered Species Near Selected Sites

<u>Species, Common Name, Habitat</u>	<u>Nearest Site to Endangered Species</u>
<i>Cystopteris bulbifera</i> Bulbed Fern Often found on gypsum outcrops	Shubenacadie-Stewiacke Boularderie Port Richmond McIntyre Lake
<i>Carex aurea</i> (flowering plant) Wet meadows and banks	Shubenacadie-Stewiacke
<i>Cypripedium calceolus</i> Yellow Lady's Slipper Usually over gypsum	Port Richmond McIntyre Lake
<i>Pteretis pensylvanica</i> Ostrich Fern Beside streams and near limestone and gypsum outcrops	Boularderie Beaver Brook
<i>Hepatica americana</i> Round-lobed Hepatica Rich hardwoods	Shubenacadie-Stewiacke
<i>Dicentra culcullaria</i> Dutchman's Breeches Rich woods and hardwood hillsides	McIntyre Lake
<i>Rhamnus alnifolia</i> Alder-leaved Buckthorn Swampy woods and boggy meadows	Shubenacadie-Stewiacke Boularderie
<i>Dirca palustris</i> Leatherwood Rich deciduous mixed woods	Shubenacadie-Stewiacke
<i>Galium tinctorium</i> Small Bedstraw Low areas along brooks, marshes, bogs	Shubenacadie-Stewiacke Boularderie
<i>Erigeron hyssopifolius</i> Fleabane Gypsum outcrops and damp cliffs	Boularderie Beaver Brook

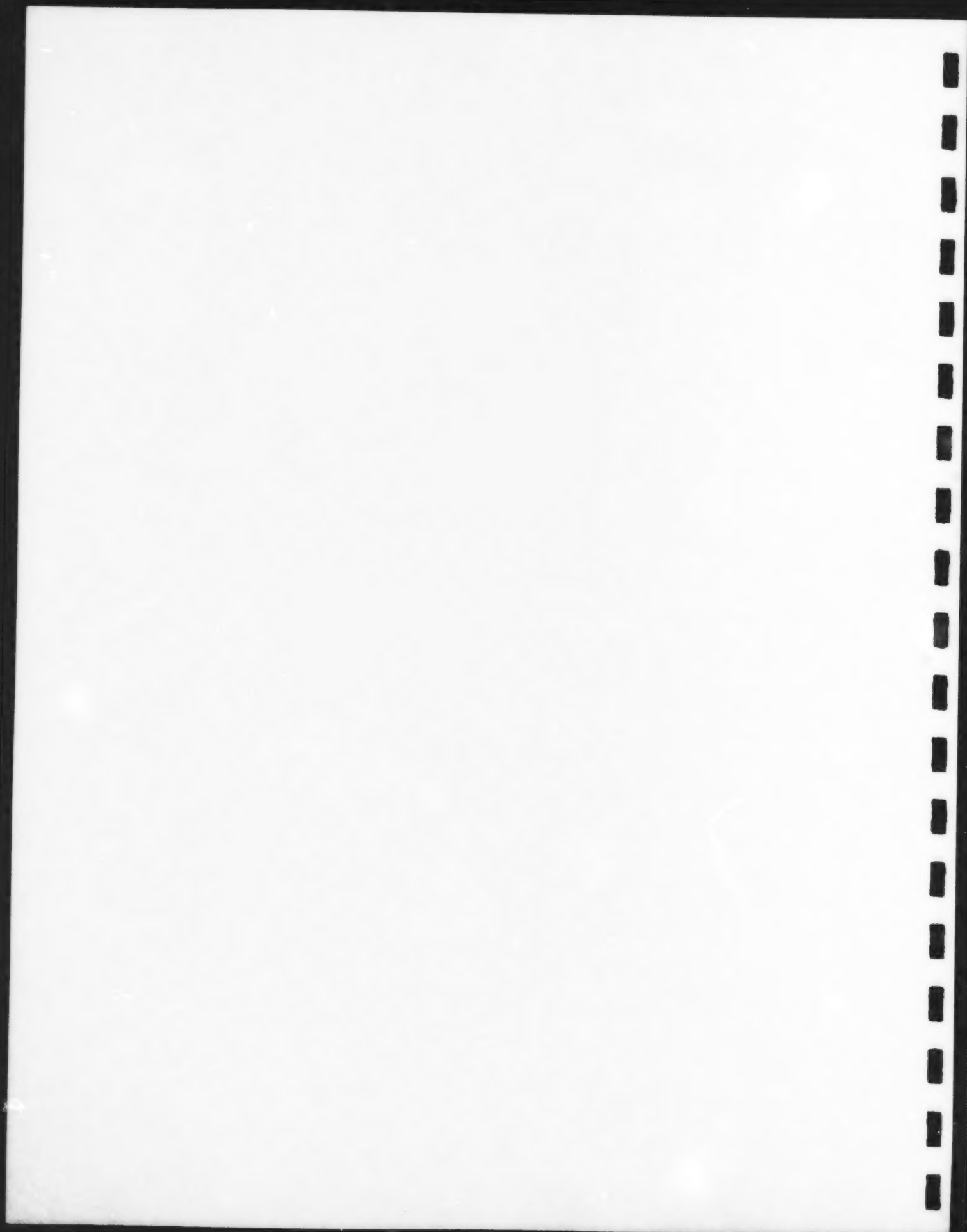
TABLE C-1 (contd.)

<u>Species, Common Name, Habitat</u>	<u>Nearest Site to Endangered Species</u>
Gyraulus parvus Lesser Ram's Horn (Small) In ponds or slow-flowing brooks	Shubenacadie-Stewiacke
Philomycus carolinianus flexouularis Snail or slug Moist places under logs	Shubenacadie-Stewiacke Boularderie
Margaritifera margaritifera Pearl Mussel Streams and rivers with gravel or sand bottoms	Shubenacadie-Stewiacke Kingsville Nappan
Sphaerium simile Bivalve Lakes or slow water in rivers	Shubenacadie-Stewiacke Nappan
Culaea inconstans Brook Stickleback Densely vegetated waters of small streams or small bog lakes	Nappan
Ambystoma laterale (Tripod Form) Blue spotted salamander Alder swamps, ponds, and slow vegetated streams	Nappan
Hemidactylum scutatum Four-toed salamander Sphagnum bogs and adjacent woodlands	Shubenacadie-Stewiacke Port Richmond McIntyre Lake
Pipistrellus subflavius subflavius Eastern pipistrelle (bat) Cave hibernator	Shubenacadie-Stewiacke Beaver Brook

Notes: Compiled from Isnor, W., 1981. Provisional Notes on the Rare and Endangered Plants and Animals of Nova Scotia. Nova Scotia Museum Curatorial Report Number 46, Halifax, Nova Scotia, 71 pp.

List does not include birds or marine species.

Locations indicate the sites nearest to where these species have been reported.



APPENDIX D

**Barge Transport of Compression Natural Gas
Conceptual Design and Economic Analysis**

APPENDIX D

BARGE TRANSPORT OF COMPRESSION NATURAL GAS CONCEPTUAL DESIGN AND ECONOMIC ANALYSIS

D.1 Conceptual Design, CNG Transport

With this concept, over-pressured gas at approximately 35 MPa would be expanded to 21 MPa and loaded into high-strength steel pipe (760 MPa yield) on a barge. Natural gas liquids, water, and H_2S , if present, would be separated during the expansion at the offshore platform. The following assumptions are made: each barge would carry 4.5 million cubic metres (160 million standard cubic feet); would be pushed or towed by tug at, on average, 26 km/h (14 knots); and would require approximately one week to make a one-way trip of 400 kilometers. This allows two days for loading (limited by production capacity) and one day for unloading. Sable Island to Boston is approximately 1000 kilometres. Trips to Maine, New Brunswick, Prince Edward Island, and Nova Scotia would be shorter.

Assuming one week per trip and 50 trips per year, this would ship 225 million cubic meters (8 billion cubic feet) per year. Because of the need to unload 4.5 million cubic meters (160 million standard cubic feet) in one day, barge destinations would require surge capacity. In Boston and other East Coast United States cities, this could probably be handled by the existing pipeline and surface tank systems. Long distance transmission lines typically operate at high pressures (14 MPa is not unusual) and are capable of absorbing large surges. In areas without existing surge capacity, it will have to be provided. Nova Scotia is well-suited to develop this capability in that it has potential surge capacity via subsurface storage in salt caverns) near each of its major industrial centers. Figure D-1 shows suggested barge routes from Sable Island.

The route to Halifax would terminate at a pipeline leading from the Bedford Basin to salt storage caverns in the Shubenacadie-Stewiacke Salt deposit near Enfield, approximately 30 km away. This is not an excessive distance for either the brine to the ocean transport during cavern development or for gas transport during distribution system. The Shubenacadie-Stewiacke deposit approximately 30 kilometers from Halifax, is well-suited for natural gas storage.

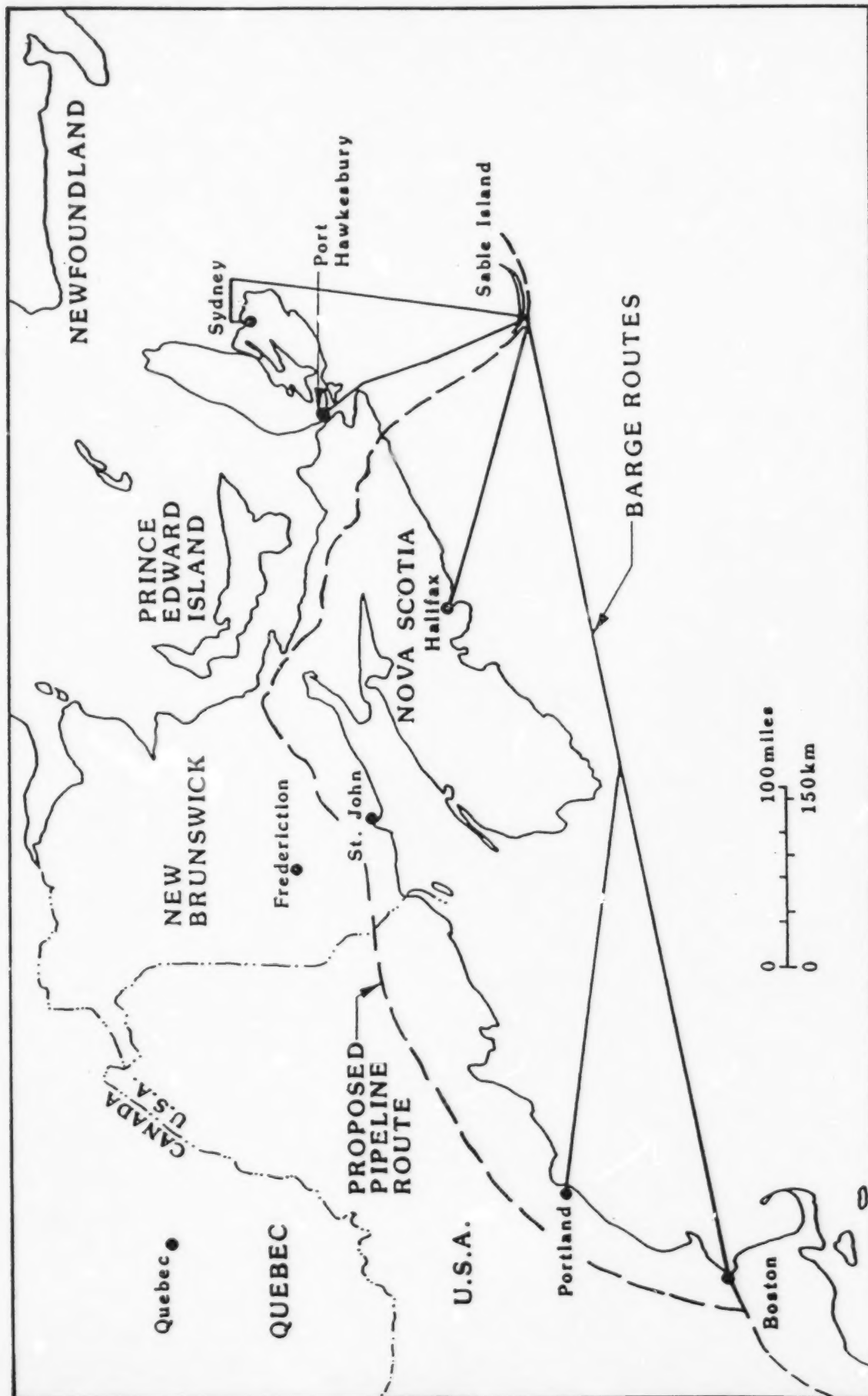


FIGURE D-1
PROPOSED COMPRESSED NATURAL GAS
BARGE ROUTES

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The route to the Strait of Canso would terminate at Port Hawkesbury and use nearby salt storage caverns. Either the Port Richmond Deposit, the McIntyre Lake Deposit, or the Kingsville Deposit are suitable for natural gas storage.

The salt deposit at Boularderie Island also shows promise as a potential gas storage site for the Sydney area.

The route to Sydney could probably terminate at an abandoned coal mine in the Sydney Coalfield. Coal mine storage of natural gas is in use in the United States and in Belgium (PB-KBB, Inc., 1982). Primary considerations in this type of existing mine storage are the depth of the top of the storage (to allow pressuring of the gas); the volume of the storage; the formation tightness and the ability to seal the mine at the entrance the storage region. The abandoned underwater coal mines in the Sydney coal field probably satisfy all of these conditions, with the possible exception of the sealing capability which would have to be investigated. The mines have the added advantage that they are close to harbour facilities and to a population and industrial center.

Barge trips to Nova Scotia would average closer to 60 trips per year, thus lowering the average gas cost to this area from that quoted earlier. On reaching the surge storage site, the gas would be allowed to expand from the barge into the dry salt cavern or mine. Gas fueled compressors would assist once the storage reached equilibrium pressure with the barge. Gas pipeline distribution systems would be required from the surge storage to customers. Commercial contracts or government guarantees would probably provide the economic basis for initial surge development. Actual salt cavern creation is discussed elsewhere; but in this case, the natural gas could be used as a roof protection pad and initial surge storage as leaching proceeds. It would require dehydration before use.

D.2 Compressed Gas Barge - Description

The compressed gas barge would have sea-going capability and 19 kilotonne capacity. Gas cylinders, made from high yield strength steel pipe would make up approximately 15.4 kilotonnes of the barge capacity. The cylinders will operate at 80 percent of internal yield pressure (21 MPa for 13 mm wall, 61 cm diameter pipe with a yield stress of 760 MPa) and

will be approximately 82,000 metres in length. This system would hold approximately 4.5 cubic metres of dry natural gas. The gas weight would be about 3080 tonnes. The balance of the 19 kilotonnes would be made up of manifolding and valving to connect the cylinders together for loading and unloading purposes. Note that the piping diameter can vary in size, but the gas volume at operating pressure will remain the same for the same total piping weight (say 15.4 kilotonnes). This occurs because wall thickness (t) must vary with the diameter (D) to yield a constant ratio t/D, at the same piping yield strength (t/D for 760 MPa yield piping with a yield an internal pressure of 28 MPa is 0.021 regardless of piping diameter).

D.3 Compressed Natural Gas - Economic Analysis

Below are estimated costs of the barge, tug, and pipe:

	Cost millions \$, Cdn. (millions \$, U.S.)
Barge (19 kilotonnes capacity)	13.3 (10.0)
Tug	6.7 (5.0)
Pipe (at \$1765 Cdn./tonne)	27.2 (20.4)
Pipe Manifolding	0.9 (0.7)
Welding (Cylinders)	2.5 (1.9)
Contingency (15%)	7.6 (5.7)
 TOTAL	 58.2 (43.7)

Thus, a capital cost of \$67 million Cdn. (\$50 million US) may be used conservatively.

Three options have been considered in determining capital outlay and expected profits. The options assume use of either one, two, or three barges. All three options include a cost of production of \$0.061 Cdn. per cubic meter (\$1.30 US per million cubic feet). This cost is conservatively based on drilling and platform cost estimates in the 1985 Nova Scotia Department of Mines and Energy's Oil and Gas Report for 11.3 million cubic meters/day (mcmd) of gas from the Venture Field. The basis for the costs in the Oil and Gas Report was four platforms with multiple well completions on each, producing 11.3 mcmd of gas, which is approximately quadruple the need in the case of the barging operation. However, by assuming a linear

cost decrease with a linear decrease in number of platforms and amount of production, the cost of \$0.061 Dcn per cubic metre (\$1.30 US thousand cubic feet) for one platform producing 2.8 mcmd appears reasonable and conservative. Dry natural gas and natural gas liquids can be delivered to any number of available markets. Table D-1 shows approximate one-way distances and sailing times from Sable Island to five potential gas markets.

TABLE D-1

Distances and Sailing Time

		Distance		Sailing Time
	(km)	(Nautical miles)	(Statute miles)	at 26 km/h (hours)
Sable Island to:				
Boston, MA	933	504	580	36
Portland, ME	848	460	530	33
Halifax, NS	303	165	190	12
Sydney, NS	300	165	190	12
St. John's, NF	740	400	460	30

Assuming two days to load and one day to unload each barge, the sailing times show that 4.5 million cubic metres (160 million cubic feet) can be delivered to any of these markets in less than a week. With three barges running in a staggered schedule, continuous production can be maintained. A summary of assumptions for the three options are presented in Table D-2.

Option I has one barge capable of carrying 4.5 million cubic metres (160 million cubic feet) of natural gas at 21 MPa (3000 psi) and traveling at an average speed of 26 km/h. The gas loading, transport, unloading and return trip is to be accomplished 50 to 60 times a year, totalling between 225 million cubic metres and 270 million cubic metres of natural gas. Options II and III have two barges and three barges,

respectively. The advantage of Options II and III is that near continuous production from the gas wells can be maintained. The continuous production will allow for a much more efficient operation without overproducing the wells, and could reduce production costs as well.

TABLE D-2

Assumptions Used in Economic Analysis

-
1. Barge and tug complete with pressure vessel large enough for 4.5 million cubic metres (160 million cubic feet) dry natural gas @ 21 MPa (3000 psi) - \$67 million Cdn. (\$50 million (U.S.)).
 2. Gas cost at the wellhead of \$0.061 Cdn./cubic metre (\$1.30 US per million cubic feet).
 3. Gas sales prices include the natural gas liquids.
 4. Barge speed of 26 km/hour.
 5. Published royalty costs equal to 2 percent of gross income.
 6. Income tax of 30 percent.
 7. Net Present Value (NPV) based on 10 percent.
 8. 20 year straight line depreciation.
 9. A 20 year loan at 8 percent annual interest rate.
 10. All currency figures are in Cdn. dollars (based on \$1.00 Cdn. = \$0.75 U.S. dollar).
 11. Analysis is for barge only; offshore production cost is lumped under 2. above.
-

Tables D-3 to D-5 summarize payback period, discounted cash flow rate of return (20 years), and Net Present Value (20 years) for the three options, at sales prices of \$0.14, \$0.21, and \$0.28 Cdn. per metre (\$3, \$4.50, and \$6 US/MCF).

TABLE D-3

Sales Price @ \$0.14 Cdn./Cubic Metre (US \$3/MCF)

Trips/Year	Payback (yrs.)		DCF ROR* (%)		NPV* at 10% millions \$ Cdn. (millions US \$)	
	50	60	50	60	50	60
Option I	6.60	5.28	14.9	19.1	26.15 (19.61)	49.53 (37.15)
Option II	6.48	5.19	15.2	19.4	54.71 (41.03)	101.49 (76.12)
Option III	6.44	5.15	15.3	19.6	83.28 (62.46)	153.45 (115.09)

TABLE D-4

Sales Price @ \$0.21 Cdn./Cubic Metre (US \$4.50/MCF)

Trips/Year	Payback (yrs.)		DCF ROR* (%)		NPV* at 10% millions \$ Cdn. (millions US \$)	
	50	60	50	60	50	60
Option I	3.28	2.66	31.2	38.4	119.59 (89.69)	169.67 (127.25)
Option II	3.21	2.61	31.7	38.9	241.60 (181.20)	325.76 (244.32)
Option III	3.19	2.59	31.8	39.1	363.60 (272.70)	489.85 (367.39)

TABLE D-5

Sales Price @ \$0.28 Cdn./Cubic Metre (US \$6.00/MCF)

Trips/Year	Payback (yrs.)		DCF ROR* (%)		NPV* at 10% millions \$ Cdn. (millions US \$)	
	50	60	50	60	50	60
Option I	2.16	1.77	47.2	57.6	213.03 (159.77)	273.80 (205.35)
Option II	2.12	1.74	47.8	58.3	428.49 (321.37)	550.03 (412.52)
Option III	2.11	1.73	48.0	58.6	643.95 (482.96)	826.25 (619.69)

NOTE: Dollar conversions based upon 0.75 \$ US = \$1.0 Cdn.

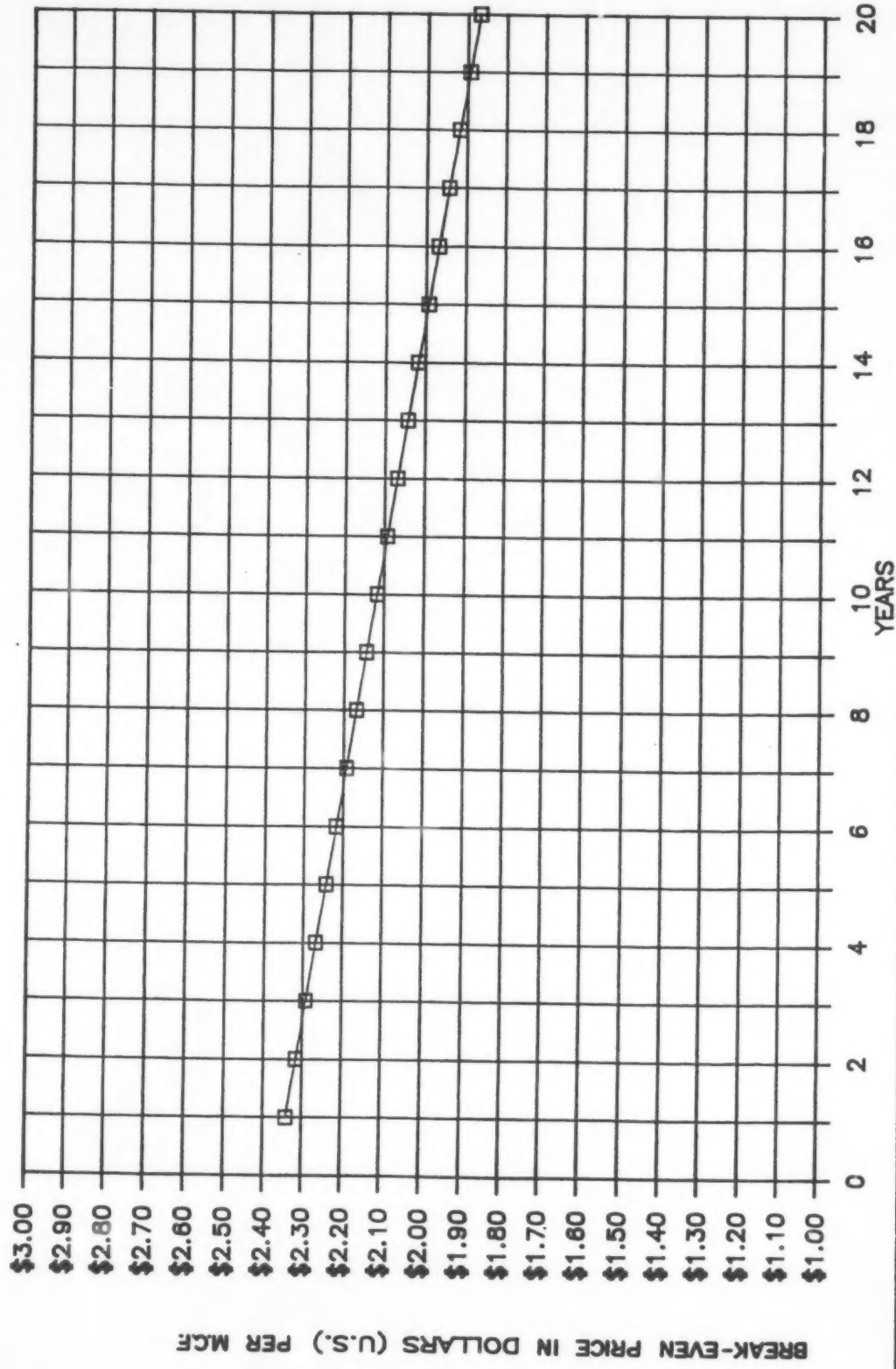
*DCF ROR - Discounted cash flow rate or return

*NPV - Net present value

Year-by-year detailed accounting for all three Options, from which these numbers are derived, showing royalties, taxes, operating expenses, etc., are available.

Expansion of CNG transport system can take place as needed in relatively small increments. This is a huge advantage over offshore pipeline systems that require much larger investments and many times more quantities of gas to be profitable. Figures D-2 and D-3 show the break-even cost of gas for 50 trips per year and 60 trips per year, respectively. This again is very competitive. Note however, that although these analyses do not include an in situ cost for the gas, the capital costs were rounded to \$67 million Canadian per barge from \$58 million estimated earlier.

NOVA SCOTIA — COMPRESSED GAS



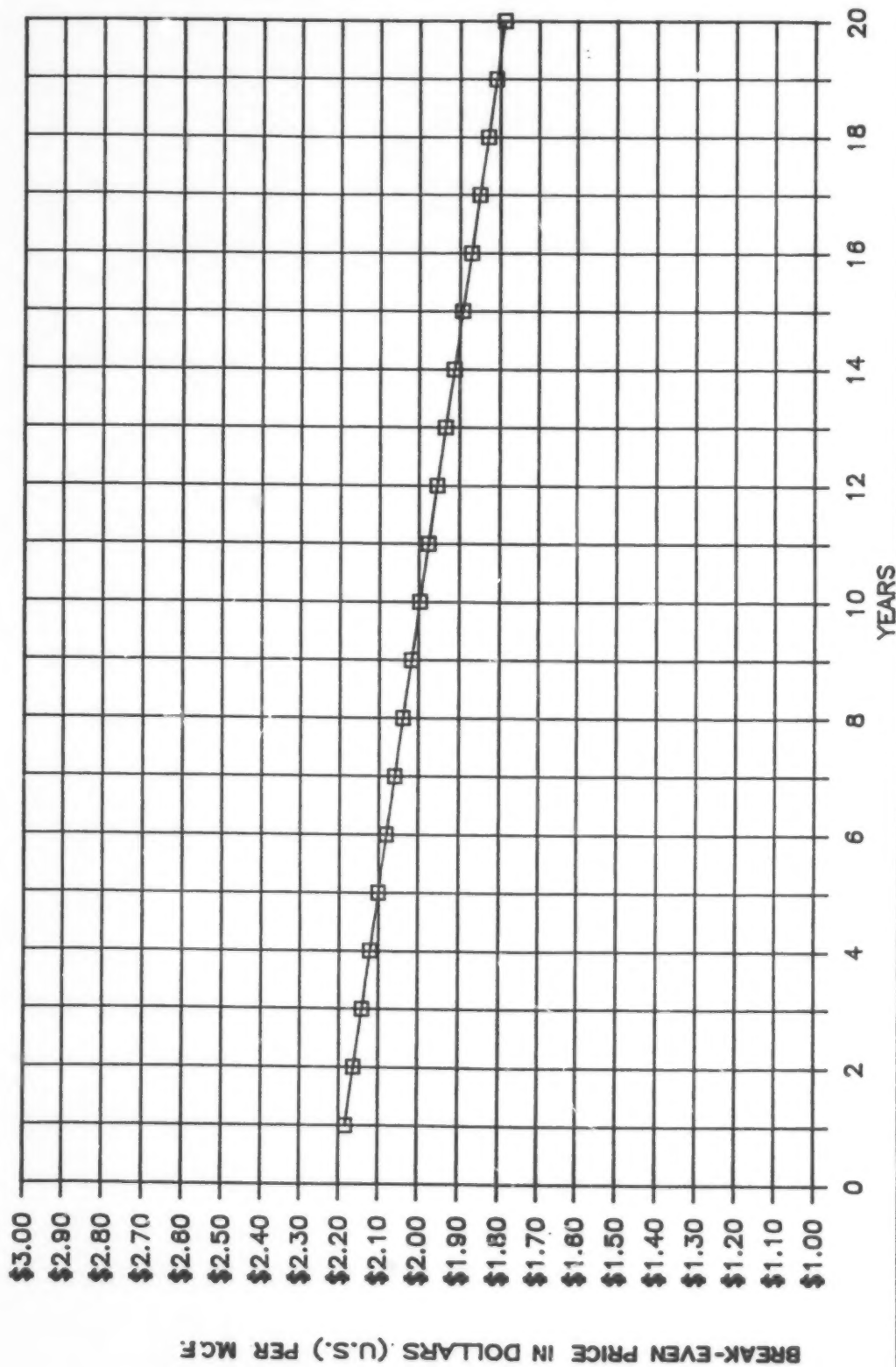
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FIGURE D-2
BREAK-EVEN PRICE
BASED ON 50 TRIPS PER YEAR

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NOVA SCOTIA — COMPRESSED GAS



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FIGURE D-3
BREAK-EVEN PRICE
BASED ON 60 TRIPS PER YEAR

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